ILLUMINATING ENGINEERING

MAY 1955

Brightness and Illumination in Enclosures

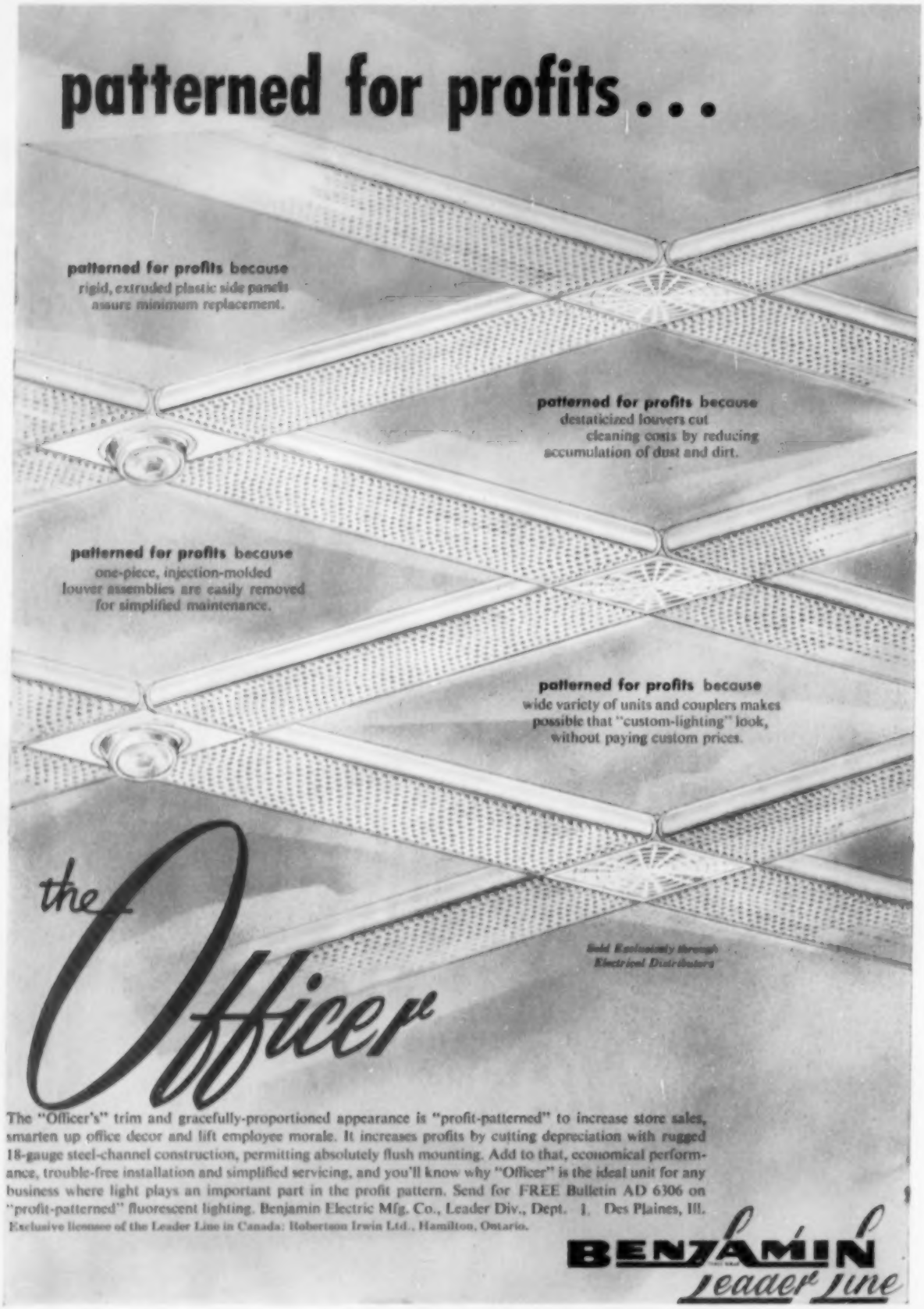
The Layman's Use of Glare Factors

Fluorescent for School Stages

High-Intensity Sources

Lighting Applications

THE JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY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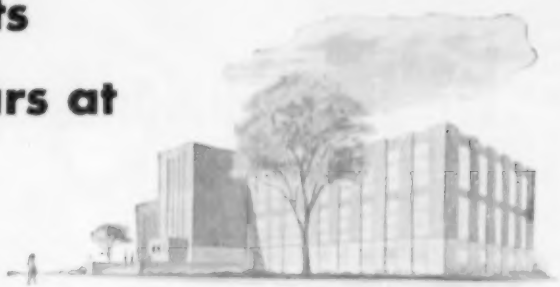

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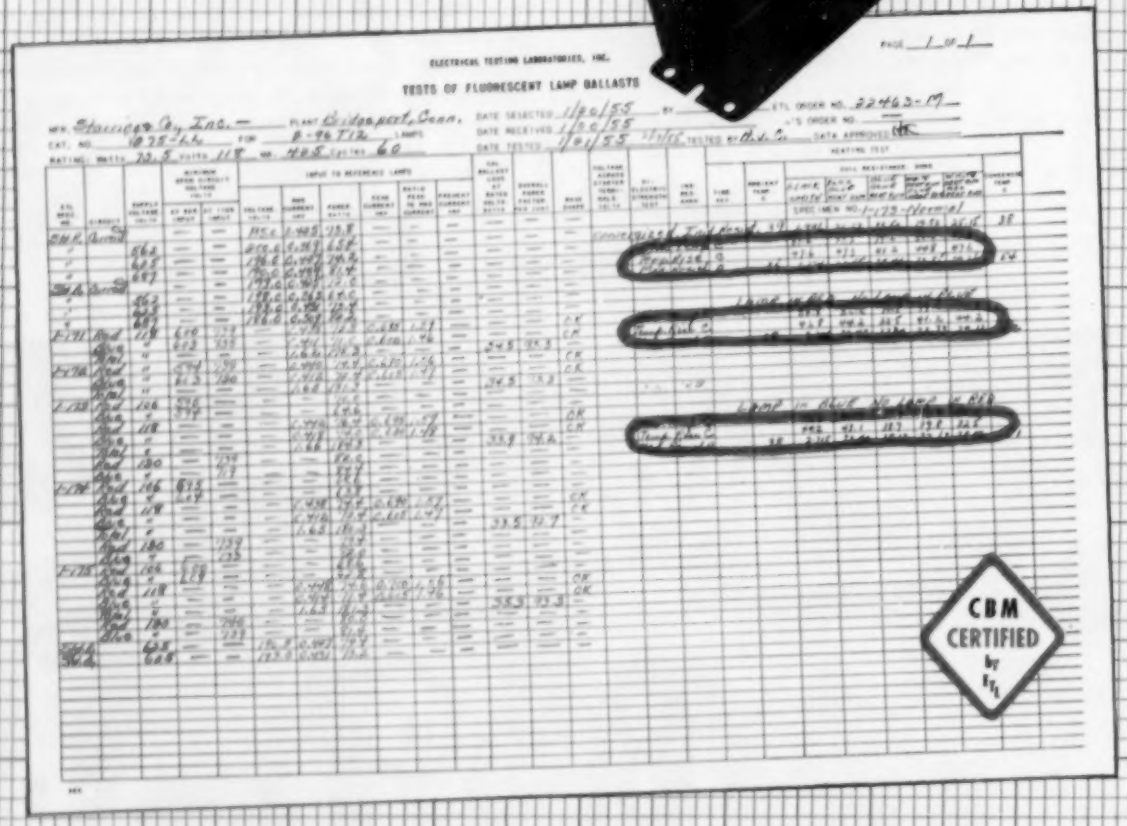

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13⅛" x 3¾" x 2⅝"
Mounting Length 13¾"
Weight 13.7 pounds

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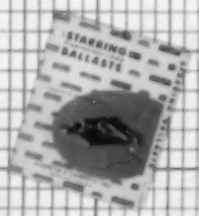

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ILLUMINATING ENGINEERING

THE JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY

MAY
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INSTALLATION: Relief Printing Corp., Boston, Massachusetts
ENGINEER: C. A. Russell, Boston Edison Co.
ELEC. CONTRACTOR: George Phelps Co.
TYPE OF AREA: Packaging and Mailing
FINISHES: Ceiling, pastel yellow
Walls, light green
CEILING HEIGHT: 14'–0"
FIXTURES: Litecontrol No. 2428 Slimline Industrial Fixture, Pendant Mounted
MOUNTING HEIGHT: 12'–0"
SPACING: 11'–0" on centers
Perimeter row of fixtures 3'–6" from wall
INTENSITY: 60 footcandles average initially

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The Layman's Use of Glare Factors

By R. D. BRADLEY

A simple explanation of the thinking behind three systems of comfort-rating for lighting installations, and how to use them.

ANYONE concerned with the specifications for any kind of lighting installation whatsoever must be able, nowadays, to evaluate the relative comfort of a proposed installation. Consideration of the "quality" of a lighting system can now, fortunately, be regarded as basic to every job.

Our fairly recent emphasis on *quality* comes partly from our increased scientific knowledge of glare and its results — and partly from the application of good sense in applied lighting. Recommended levels of illumination we know are important to good seeing — but we cannot hope to see their wide acceptance until *quality*, or comfort of vision, is a planned part of the system.

How does one evaluate glare; and, how control it? Several of the scientists in illuminating engineering have suggested answers which this article will attempt to simplify. One simple demonstration, however, will illustrate the physical reactions people have to the presence of glare. Seat yourself at a desk and proceed to read or write for a period of five to ten minutes. Then put your hat on and pull the brim down to act as an eyeshade. If you have a physical reaction of relief, *direct glare* is present in rather large quantities. Cover the work surface (desk) with a gray cloth and proceed to do the same work. If you again experience a sensation of improvement or relief, you may be sure *reflected glare* (and/or excessive contrast) is present.

Both of these types of glare can be described as "discomfort glare" and, depending on the length of time we are exposed to them, are tiring, cause eyestrain, and absorb excess energy. Even milder forms of incipient glare are of practical concern to us, as the effects are cumulative, causing fatigue through eyestrain and possibly permanent ill effects, if experienced for prolonged periods.

There have been, and still are, numerous attempts to control direct and reflected glare by "rule of thumb" methods. Not many years ago, for instance, indirect lighting was felt to be the answer to all glare problems. As higher levels of illumination were desired, however, it was found that somewhere around 50 footcandles was the highest practical limit at which comfort could be maintained with an indirect system. This is still true, and is the case also with luminous ceilings where large-area brightness can be viewed by the worker.

Direct illumination (with louvers and fluorescent sources) has been accepted as doing a practical job at low cost, where reflected glare can be controlled by type or orientation of task. Obviously, compromises were worked out using direct, indirect or semi-indirect systems, trying to find satisfactory conditions at the least cost. These attempts point out that *all* of the basic causes must be considered if one is to predict comfort level compatible with task needs and economics.

Economics should not be a part of basic theoretical analyses of glare problems. On the other hand, from a practical point of view, we know that they will play a definite part in the purchase of a lighting system. It might be noted here that *all* tasks do not need complete glare-free lighting (100 per cent on the Visual Comfort Index or below 15 on the Glare Rating Scale). Certain types of high-traffic sales areas even *want* direct glare. The basic problem becomes one of engineering, to arrive at the most economical solution to provide the range of comfort actually needed for the particular area and tasks being performed in the area. For this we should know:

(1) Physical characteristics of area.
(2) Reflection factors of surfaces in area.
(3) Type of task to be performed in area.
(4) A method of numerical evaluation of these conditions.
(5) A key to the selection of a lighting system, using this information.

It is the last two items that we are considering in this article.

Reflected glare, being largely the property of task or desk surface, is comparatively easy to con-

AUTHOR: Director of Engineering, Day-Brite Lighting, Inc., St. Louis, Mo.

Room Width	Room Length	Luminaire Mounting Height							
		8′ 6″		10′ 0″		13′ 0″		16′ 0″	
		End-wise	Cross-wise	End-wise	Cross-wise	End-wise	Cross-wise	End-wise	Cross-wise
15	20	13	12	11	11	8	8		
	30	14	13	12	11	10	9		
	40	14	14	13	12	11	10		
	60	15	15	13	13	11	10		
	80	15	15	13	14	11	11		
20	20	14	13	12	11	9	9	6	7
	30	15	14	13	12	11	10	9	8
	40	15	15	14	13	12	11	10	9
	60	16	16	14	14	12	11	11	10
	80	16	17	15	14	12	12	11	10
	100	16	17	15	15	13	12	11	10
30	40	16	15	15	14	13	12	11	10
	60	17	17	15	15	14	13	12	11
	80	17	18	16	16	14	13	13	12
	100	17	19	16	17	14	14	13	12
	150	17	21	16	18	14	15	13	13
40	40	16	16	15	14	13	12	11	11
	60	17	18	16	16	14	13	13	12
	80	17	19	16	17	15	14	14	12
	100	17	21	16	18	15	14	14	13
	150	18	22	17	19	16	16	14	14
60	60	17	18	16	16	15	14	14	13
	80	18	21	17	18	16	15	15	13
	100	19	23	17	19	16	16	15	14
	150	20	25	18	21	16	17	15	15

Figure 1. Harrison-Meaker Glare Factor System. Factors indicated are for 50 footcandles; reflectances of: ceiling 75%, walls 50%, working plane 15%; using 75-watt two-lamp louvered luminaires with 35° crosswise shielding and 25° endwise shielding.

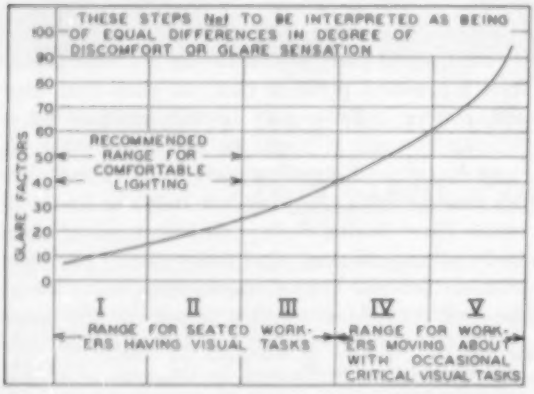


Figure 2. Glare Factor Evaluation Chart (Harrison-Meaker system). Comfort conditions in each section of curve are:

I — Probably comfortable for all. Aesthetic preference may influence personal appraisal.

II — Comfortable for most workers seated in fixed positions for long periods.

III — Marginal range for offices, schools, etc. A few occupants may need re-locating to more favorable positions.

IV — In offices and schools approximately one-half seated occupants may experience some discomfort.

V — Considerable discomfort may be experienced by seated workers having prolonged mental and visual tasks.

trol. We can change the surface of the desk top, and to a large extent control reflected glare from the task by choice of paper and orientation. Obviously, reflected glare is a separate problem from direct glare, and must be treated independently. Direct glare, being largely a characteristic of room reflection factors and light sources in the field of view, poses another problem wherein the source is usually the greatest variable.

Systems of Evaluation

Harrison-Meaker Glare Factor System

Harrison and Meaker[1] have gone back to basic glare formulation, conceived by Holladay[2] some 15 years or more ago. These researchers devised a numerical method of evaluation based on an arbitrary unit of glare, of:

1 square inch at 1000 footlamberts
10 feet from observers
10 degrees above horizontal line of vision with
10 footlambert surround brightness

Next, certain surround conditions (reflection factors of ceiling, walls, desk and floor) were assumed, and an arbitrary (50 footcandle) level was selected upon which to base calculations. They then devised a method of adding the area-brightness of all light sources affecting the observer so that the cumulative effect could be expressed as affecting an observer in the rear center of the room. Obviously, all personnel cannot be seated in this position simultaneously, so that this represents the most pessimistic condition. Guth[3] contributed to this by additional experimentation, modifying the original formula for additive and position effects. These numbers are known as "Glare Factors" or "Glare Ratings." (See Fig. 1.)

Theoretical "comfort" was checked by actual observation and seemed to check quite well. (Fig. 2 shows guideposts depicted in the form of a curve devised by this author.)

As an example of the use of the Glare Rating System, and the tables in Fig. 1, assume a classroom or small office 30 feet by 40 feet, with a 10-foot mounting height, to be illuminated to 50 footcandles (maintained). We will assume this room to have a 75 per cent reflection factor ceiling, 50 per cent reflection factor walls, and 15 per cent reflection factor working plane and floor. By selecting the proper line in Fig. 1 in the 10-foot mounting height column, we note that the endwise glare factor is 15 and the crosswise glare factor is 14. By referring to Fig. 2, we note that we are in the range where "comfort for all" is obtainable. We also note that there is very little choice in whether we view the fixtures endwise or crosswise.

Room Width	Room Length	Units Viewed Crosswise — Height Above Floor (Feet)				Units Viewed Endwise — Height Above Floor (Feet)			
		8½	10	13	16	8½	10	13	16
15	20	92%	94%	97%		94%	95%	97%	
	30	88	92	96		94	95	96	
	40	87	90	94		94	95	96	
	60	83	88	92		94	95	96	
	80	81	87	92		94	95	96	
20	20	91	94	97	97%	94	94	96	97%
	30	87	91	95	96	94	94	96	96
	40	85	88	93	96	93	94	96	96
	60	80	86	92	94	93	94	95	96
	80	77	84	90	93	93	94	95	96
	100	74	82	89	92	93	94	95	96
30	40	82	87	92	94	92	93	94	96
	60	96	82	89	92	92	93	94	95
	80	71	79	87	91	92	93	94	95
	100	67	76	85	90	92	93	94	95
	150	64	71	82	87	92	93	94	95
40	40		86	92	94		92	94	95
	60		80	87	92		92	94	94
	80		76	85	89		92	94	94
	100		72	83	87		92	94	94
	150		66	78	85		92	93	94
60	60			86	90			93	94
	80			83	87			92	94
	100			79	86			92	93
	150			72	80			92	93

Figure 3. Visual Comfort Index (Meaker-Oetting) giving "percentage of people comfortable." Chart is for 50 footcandles; using louvered luminaires with diffusing glass sides and crosswise shielding of 35° and lengthwise shielding of 25°.

V.C.I. System

Later, Messrs. Meaker and Oetting[4] carried this system further and expressed the numbers as "per cent of people comfortable" (assuming that all persons were seated on center line at rear of room). This is known as V.C.I., or Visual Comfort Index. (See Fig. 3.) No guideposts were established to help the user decide what was good or bad for the particular application at hand. Both Glare Factors and V.C.I. are numerical systems which are tabulated for light-source types (luminaires), assuming room conditions to remain constant. These are easily used by anyone interested, and will help evaluate the proposed job from the comfort standpoint. For instance, to evaluate the comfort of a room 30 feet by 40 feet, with a 10-foot mounting height, by the V.C.I. system, we will follow the same procedure as in the previous illustration. Using Fig. 3 and again assuming this area to be a small office or schoolroom, we note that the Visual Comfort Index, when viewed crosswise, is 87 per cent and, when viewed lengthwise, is 93 per cent. As no guideposts are established, we may conclude that either orientation is satisfactory for the tasks to be performed, but will note that the lengthwise viewing is to be preferred over the crosswise.

Logan-Lange V.C.F. System

Logan and Lange[5] started with the basic concept that nature has evolved the human eye and visual senses to be well adapted to conditions of nature as man developed outdoors. Their studies led to subdividing fields of view into zones and establishing brightness limits for these zones, as found in nature. A method of relating these conditions to indoor equivalents was devised, using interreflection calculations formulated by Moon and Spencer.[6] Basic calculations and tabulation of results are not dissimilar to Harrison-Meaker, and the results are tabulated as per cent of persons comfortable. The same observer position was used, although there was a considerable difference in determining adaptation level. Also, higher ceiling, floor and desk reflection factors were assumed. This system is known as V.C.F. (Visual Comfort Factors). While these two systems are not directly comparable, their general characteristics are quite similar. These researchers indicate 75 per cent to be a borderline between comfort and discomfort. (See Fig. 4.) Anyone wishing to evaluate the comfort of a proposed lighting installation may use these tables in a manner similar to that for Glare Ratings or V.C.I. As an example, let us assume the same room as used previously, that is a small office or schoolroom 30 feet by 40 feet, with a 10-foot mounting height, and refer to Fig. 4. We note that we have 95 per cent V.C.F. crosswise and 87 per cent endwise. These researchers indicate a borderline of 75

Room Width	Room Length	Crosswise — Ceiling Height				Endwise — Ceiling Height			
		8½′	10′	13′	16′	8½′	10′	13′	16′
		%	%	%	%	%	%	%	%
15	20	100	100	100	99	97	91	92	95
	30	99	99	99	98	96	90	91	94
	40	98	98	98	98	96	89	90	93
	60	97	98	97	98	95	88	89	92
20	20	100	100	99	98	97	90	91	95
	30	98	98	98	97	96	88	89	93
	40	96	97	97	96	95	87	88	91
	60	95	96	96	96	94	86	87	89
	80	94	95	95	95	93	85	86	88
30	40	94	95	95	96	95	87	88	90
	60	89	90	91	92	93	85	85	87
	80	85	86	88	90	91	83	82	84
	100	82	84	86	88	89	82	80	82
40	40	91	93	93	94	93	85	85	88
	60	87	88	90	91	91	83	82	84
	80	83	85	87	88	89	81	79	81
	100	80	82	84	86	87	80	77	79
60	120	76	79	81	83	85	78	75	77

Figure 4. Visual Comfort Factor (Logan-Lange) giving "percentage of people comfortable." Chart is for 10-100 footcandles, with reflectances of: ceiling 80%, walls 50%, floor 30%.

per cent, again leading us to the conclusion that either orientation is satisfactory, but that the crosswise viewing is to be preferred. It should be noted that these tables were compiled, assuming higher reflection factors of ceiling and floor than used in the Harrison-Meaker calculations.

Interflection System

Spencer[7] has been the chief proponent of an interflection method of calculating room intensities and brightnesses. By this system, it is contended that a uniform (one-to-one) field brightness is ideal and that for practical limitations a one-to-three brightness ratio is desirable and denotes comfort, while ratios greater than this are outside comfort limits. Each room must be analyzed and calculated. No set of tabular data is available for luminaire types.

Practical Use of Evaluation Systems

With the increasing appreciation that comfort is a "must" for a lighting installation, more and more laymen are interested in evaluating the comfort factors of a proposed system. They are not versed in all of the many factors affecting comfort, but they would like a practical, easy method of judgment, so that they may install a system having sufficient comfort for the tasks being performed, at the least possible owning cost. A review of the three systems described may help them choose such a method.

Comfort is a property of the individual and, therefore, a wide variable. No two people will experience the exact sensation under the same circumstances. Comfort-rating systems, therefore, are inexact in this respect. It is preferable to think of comfort ratings in ranges and not try to establish hard and fast borderlines. The systems are not final, and more information is being added as experience is gained in their use and new experimental data become available.

Summary

To summarize, there are three systems available today, two of which are prepared in tabular form for easy use by the layman. These systems are as easy to use as utilization tables, and all jobs requiring comfort should be rated to provide the highest level economically possible. Actual experience will show the useability of these methods.

A universal system is being studied by I.E.S., and may soon be adopted, which may be used by all, so that all numerical values would be comparable.

The older methods of trying to assure comfort by specifying maximum brightness within certain zones leads to some irrational conclusions, mainly because a great many influential factors are overlooked.

Curves of average brightness, or average brightness squared (candles per inch^2 or footlamberts^2) are quite helpful in visualizing comfort from luminaires, but are lacking in that they fail to consider several important factors which directly influence the evaluation of a comfort situation.

References

1. Harrison, Ward: "Glare Ratings." ILLUMINATING ENGINEERING, Vol. XL, No. 8, p. 525 (September 1945).

2. Holladay, L. L.: "The Fundamentals of Glare and Visibility," *Journal of the Optical Society of America*, p. 271, 1926.

3. Guth, Sylvester K.: "BCD Brightness Ratings in Lighting Practice," ILLUMINATING ENGINEERING, Vol. XLVII, No. 4, p. 184 (April 1952).
Luckiesh, Matthew and Guth, S. K.: "Brightness in Visual Field at Borderline Between Comfort and Discomfort (BCD)," ILLUMINATING ENGINEERING, Vol. XLIV, No. 11, p. 650 (November 1949).

4. Meaker, Phelps and Oetting, R. L.: "Visual Comfort Index Data and Tables — Their Meaning and Use in Lighting Design," *Bulletin LS-108*, October 1953, General Electric Co., Lamp Division.

5. Logan, H. L. and Lange, A. W.: "The Evaluation of Visual Comfort Data," ILLUMINATING ENGINEERING, Vol. XLVIII, No. 4, (April 1952).
"Visual Comfort Tables," Department of Applied Research, Holophane Co., New York, N. Y., January 1954.

6. Moon, Parry and Spencer, D. E.: "A Simple Criterion for Quality Lighting," ILLUMINATING ENGINEERING, Vol. XLII, No. 3, p. 325 (March 1947).

7. Spencer, D. E.: "Comparative Analysis of 'Comfort' and 'Glare'," ILLUMINATING ENGINEERING, Vol. XLIX, No. 1, p. 39 (January 1954).

I.E.S. National Technical Conference

September 12-16, 1955

Hotel Statler **Cleveland, Ohio**

One Way to Light a Refrigerated Showcase

By JAMES F. FINN

ABOUT FOUR years ago I became interested in lighting and color applications for walk-in refrigerated showcases. The particular job that inspired this interest was a florist whose business location was near a bus stop. During the inevitable wait for the bus in the morning, people would make use of his windows for a makeup mirror. Actually, the window was a better mirror than a display. The black background wall and floor in the walk-in refrigerated showcase, located on the back wall facing the rear of the front windows tended to create this mirror effect, the reflections completely obscuring the display.

Lighting consisted of one 40-watt fluorescent daylight lamp providing about 12 footcandles, contrasted with general lighting of 25 footcandles from unshielded fluorescent units in the store interior. This florist had twice as much illumination for his interior lighting as he had in the showcase. In addition, the unshielded fluorescent general lighting units were imaged in the glass of the refrigerated showcase. The color effect from the daylight fluorescent lamp and black interior was most uncomplimentary to the flower display. Bad as they were, these conditions are rather typical of lighting and color conditions in many florists' refrigerated showcases.

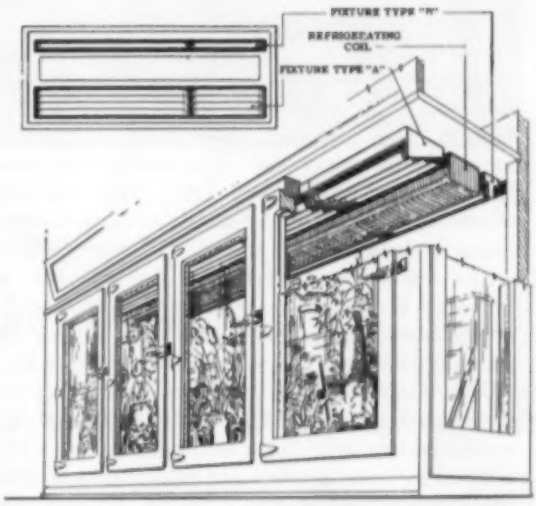


Figure 1

Suggested Technique

Refrigerated showcases and wallcase lighting should have three times the level of the general lighting system in the store. This is a minimum requirement of recommended practice which should be observed for maximum attraction at point of sale. Florists (and other store owners) should avail themselves of the services provided by local utilities and others, for illumination readings and counsel.

Luminaire "A" in Fig. 1 is a typical fixture type

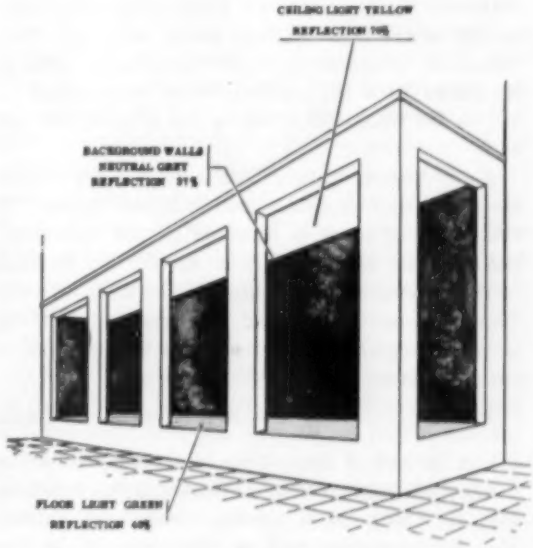


Figure 2

From a talk presented February 1955, before the Michigan Retail Florists Convention, Detroit, Michigan. AUTHOR: Detroit Edison Company.

suitable for interior lighting of refrigerated showcases. This type of luminaire is angled to provide light for both the front and rear of the showcase. The number of lamps per fixture may vary from two rows to four rows or more, depending on the illumination level of the general lighting. When there is a refrigerating coil obstructing the distribution of light from a fixture such as "A," causing shadows on the back wall, then a type such as "B" may be installed as indicated in Fig. 1. This will minimize shadows and add to the backwall brightness, thus reducing mirror images in the showcase glass, and mirror reflections in the front show windows, especially when the refrigerated showcase is located on the back wall facing the rear of the front windows.

Maintained temperatures of 40°F to 45°F in refrigerated showcases affect light output of fluorescent lamps adversely. Fluorescent lamps operate at highest light output when the bulb temperature is between 100° and 120°. This condition occurs when the surrounding air in natural circulation is between 70° and 80°F. Where strong drafts conduct heat away from the bulb such as in forced air circulation, light output may fall to approximately a third of normal light output. By partially enclosing lamps in a unit similar to type "A" in Fig. 1, the bulb wall temperature may rise approximately 20°F for a two-lamp fixture and approximately 40°F for a four-lamp fixture. This temperature rise increases the light output of these lamps closer to normal light output. These figures are taken from laboratory observations and do not describe many influencing factors in practical installations. The purpose of this lamp temperature discussion is to point out principally that light output of the same wattage lamps will vary from the colder temperature inside refrigerator cases as compared with the average room temperature of 70° to 80° where the light output is rated 100 per cent.

As to color of lamps, Deluxe Cool White lamps are in my opinion best suited to flower display. If this color of lamp is installed in the showcases, however, the same lamp color should also be used in the general lighting system in the store interior. Flowers examined under the general lighting should always appear the same as they did inside the show case.

Colors for Interior of Cases

One method of applying color techniques to the interior of refrigerated showcases is exhibited in Fig. 2. These colors are borrowed from nature. The yellow ceiling with a reflectance of 70 per cent symbolizes sunlight, thus adding some yellow highlights to the flowers. The gray neutral background (reflectance of 37 per cent) provides a neutral background color of good contrast for all colors. The floor of light green (reflectance 40 per cent) emulates the green grass background of nature. The reflected green light from the floor compliments the green foliage of the flowers displayed enhancing a three dimensional display effect.

With neutral gray walls of say 37 per cent reflectance, the reflection of light from the wall is increased about five times over that from black walls and floor, which might be of the order of 7 per cent reflectance. The light green floors increase light reflection from the floor to the flower display approximately six times over that for black.

Shielded fixtures are a requirement to minimize direct viewing brightness and help to minimize glaring reflections in the glass of the showcases. Fixture location and shielding of bare lamps in fluorescent fixtures are particularly important in accomplishing a visually pleasing interior which will help to emphasize the attraction of flowers displayed in the refrigerated showcases.

Window lighting fixtures should be shielded from view in the interior of the store. This can be done by valances or louvers on lighting fixtures, which help to reduce glaring reflections in the glass of all showcases facing the windows.

The attraction, appraisal and volume sales of flowers displayed may well depend to a large extent on the effectiveness of light and color as it is integrated with the store front, window and displays, store interior and the focal point of sale — the refrigerated showcase display.

I.E.S. Emblem

The official emblem of the Illuminating Engineering Society is available to members in 14-karat gold, lapel screw back buttons, in the miniature ½" size, at only $3.50 each including taxes. Blue background for Members, red background for Associate Members. Order from Illuminating Engineering Society, General Office, 1860 Broadway, New York 23, N. Y.

Functional . . . Flexible

Dramatic . . . and Dignified

Lighting Design for a Church

By ARTHUR SIEGAL

A SPIRIT of cooperation and enthusiasm on the part of the church Building Committee made the lighting of University Presbyterian Church an unusual and gratifying experience for me. They set out with the idea of making the lighting a useful tool rather than merely decorative, and, with the minister, visited and studied other churches to select features they would like in their own. All this presented an opportunity to apply ingenuity and modern techniques within reasonable limits of cost.

General illumination in the nave of the church is from a combination of recessed reflectors and coves on each side. Over the main seating area, 500-watt recessed mirrored glass reflectors are used with 200-watt matching units over the balcony. Under the balcony, 24-inch recessed dome lights use 200-watt lamps. The coves run full-length on each side of the main seating area, at about 30 feet above floor level, with 150-watt PAR floods spaced on 12-inch centers. Swivel sockets are mounted on a continuous raceway, allowing any desired setting of lamps, as well as prefabrication of the entire assembly. The entire strip on each side was installed as a complete unit assembly. Lamp spacing is such that the desired light level is achieved with approximately 90 volts at the socket, giving an expected life of 12,000 hours for the lamps, or about 12 years under the present operating schedule. All recessed lighting and the coves are controlled by motor-driven dimmers of the auto-transformer type, with one set on the recessed lighting and another on the coves so that they may be varied independently.

The minister expressed a desire to have a system whereby a procession down the center aisle could be followed by light while general illumination was at a low level. For this purpose one row of recessed units was placed directly over the aisle and a group of transfer switches installed. Their function is to remove each light in turn from the dimmed circuits and reconnect it to the full voltage circuit.

AUTHOR: Solo Electric Company, Seattle, Wash.

Foyer

Chapel

At the forward end of the nave are the pulpit, altar, organ console and choir area. Seven 500-watt adjustable pin-hole lights are here controlled by two dimmer units, so that either altar or choir can be highlighted. The pulpit is lighted by one of the 500-watt recessed reflectors which has its own transfer switch, so it can be spotlighted while all other lighting is at a low level.

Behind the choir is a large leaded glass window depicting a Biblical scene. To enhance its beauty at night the lead was given an overlay of gold foil and was floodlighted from the interior. The minister conceived the idea that it would be even more beautiful if he were able to play color upon the window. This was accomplished by installing a vertical bank of fifteen 150-watt PAR floods on each side of the choir. Louvers in hooded swivel sockets shield the choir from the direct rays and allow the use of color screens. The entire bank is concealed from the front by partially false columns. The 15 lamps are divided into five groups of three, each group being individually controlled. One group has no color screens, and the others have red, blue, green and amber. Each bank is operated by a motor-driven dimmer with a special automatic control circuit. Each side can be controlled separately or can be set up to vary from full intensity to zero, together or alternately, with variations in color combinations. With no other illumination, a great number of variations of color, reflections and refractions are obtained. This scheme of operation has been used for periods of "silent meditation" for five to ten minutes at a time.

Just below the window a large stone carving of The Last Supper is set into a recess, with a ring of lumiline lamps around the inside edge of the opening giving a shadow-box effect.

A foyer to the nave of the church is used for display of books and other materials offered to the congregation. Here indirect cove lighting is supplemented over the display cases by adjustable recessed floods using 150-watt PAR lamps. The cove units are made of surface raceway with lampholders on 15-inch centers using 60-watt lamps.

A small chapel is lighted by a combination of 200-watt recessed floods and coves with 75-watt lamps mounted on 18-inch centers. Here the altar is highlighted by three swivel hood lampholders concealed by an overhang.

Throughout the church, the recessed equipment that cannot be reached from the floor is relamped from a standing room attic. Dimmer motors are controlled by low voltage wiring and relays from a control room overlooking the nave. Dimmers are mounted adjacent to the main distribution panel and are connected to feeders supplying breaker panels at approximate centers of load.

Congregation and visitors alike have expressed much praise for the lighting installation, which is for me the final pleasure in designing functional, flexible, dramatic and dignified lighting for a church.

Fluorescent Stage Lighting For School Auditoriums

By WILLIAM TAO

DEMAND for at least a minimum amount of stage lighting in elementary schools and community centers is reflected through projects built in recent years. The majority of these buildings are equipped with colored border, foot, or spot lights. Ceiling border lights using 75- to 150-watt lamps spaced on 6-inch centers are the basis of all. They are usually equipped with a minimum of three colors, either red, white and blue, or red, amber and blue, or red, green and blue. It has long been advocated that since red, green and blue are the three primary colors of light, this combination should be used for producing any desired colors of mixture as well as white light by the proper mixing of all three primary colors. However, this combination is rarely used, principally because of two reasons:

(1) The transmittance of filters is different for different colors. For instance, that of red filters ranges from 15 to 20 per cent; green — 5 to 10 per cent; blue — 3 to 5 per cent; and amber — 40 to 60 per cent.[1] It is evident, in order to produce a white mixture, the wattage for different colored lights must be considerably different, and the transmittance of filters must be properly selected and rigidly controlled.

(2) Due to the low transmittance of these filters, an average of at least ten times as much wattage would be required to produce white light of the same intensity as if no filters were used.

Therefore, the most commonly used color combination for three-color arrangement is usually red, white and blue, and that of four-color arrangement is red, white, blue and green, or amber.

Since the introduction of colored fluorescent lamps, a new field of technique has been opened. There are five standard color fluorescent lamps on the market — red, blue, green, gold, and pink. As with white fluorescent lamps, the colors are produced from a selection of phosphor without using filters (with the exception of red and gold lamps). Consequently, the efficiency of colored fluorescent lamps is very high in comparison with the same color incandescent lamps with filters.

By the proper arrangement of different colored lamps, a continuous row of fluorescent fixtures may be used to replace filtered incandescent border lights of considerably higher lumens output per watt. Of course, this does not mean that fluorescent border lights will definitely replace filtered incandescent. One of the main disadvantages is the saturation of colors. Blue and green fluorescent lamps are not of saturated spectrum color, being only approximately 60 per cent in saturation. In many instances, deeper or more saturated colors are essential for dramatic effects. Filtered incandescent is, therefore, ideal in this respect.

Another problem in fluorescent lighting is the brightness control. Dimming devices of fluorescent lamps have been introduced on the market only in recent years. One of the typical dimming devices is the thyratron dimmer, which is considerably more expensive than the simple auto-transformer type used in incandescent systems. However, new low cost dimmers for fluorescent circuits are being made. One of them is known as Kershaw Simplified Circuit,[2] incorporating a variable-reactance in the control circuit. Another method of dimming is by using regular auto-transformers in the control circuit, but in the meantime, special secondary windings are incorporated in the ballast transformer to keep the electrodes at proper operating temperature.[3]

It is believed the above described methods, when manufactured in mass production, will lower the cost of dimming of fluorescent lamps to a price comparable with that of incandescent. The following lists the advantages of each system.

For Fluorescent:

(1) Low wattage for higher illumination level.

(2) A desired mixture of color may easily be accomplished by the proper combination of lamps.

(3) Cooler operating temperatures due to the lesser amount of radiated heat and hence, less discomfort for people on stage, especially in hot weather.

AUTHOR: Associate, C. J. Smith and Co., consulting engineers; Electrical Engineer, Board of Education, St. Louis, Mo.

For Filtered Incandescent:

(1) High saturation in blue and green to produce more dramatic effect.

(2) Easy for distribution control, whereas it is almost impossible to have spot lights with fluorescent system.

The nomograph on Standard C.I.E. Chromaticity Diagram[4] indicates the locations of the five standard colored lamps. The result of a mixture of different numbers of equal wattage color lamps can be read directly on the nomograph.

The mixture of any two colored lamps lies along a straight line connecting the two colors on the diagram. The exact point of mixture depends upon the number of lamps of each color used. The numbers indicated on the straight line joining any two colored lamps indicate the ratio of these lamps. For example, on the line joining green and blue, the location marked "5" near the blue location indicates the result of mixture by using 5 blue lamps to every equal wattage green lamp. The same principle may be applied to any other color combinations. To save space the reader is advised to refer to "Fundamentals of Light and Lighting" published by the Lamp Department of General Electric Company. This diagram may be used for lamps of all major manufacturers having approximately the same efficiency and complying with government standard color definitions.

Figs. 3 and 4 are the plans of a typical school stage. Descriptions of each item on the plan are given below these figures. The lamps on each border are wired according to the lamp schedule given in Table I. They may be rearranged in a simpler manner if funds are limited.[5] If the stage is different in size and depth than the one shown, the length and number of borders shall be varied accordingly.

It can be seen that the proportioning of blue: red:green:yellow is of the ratio 1:2:2:3. With this arrangement the mixture of color can be obtained shown in Table II.

This fluorescent system has been installed in St. Louis public schools and it has proved very satis-

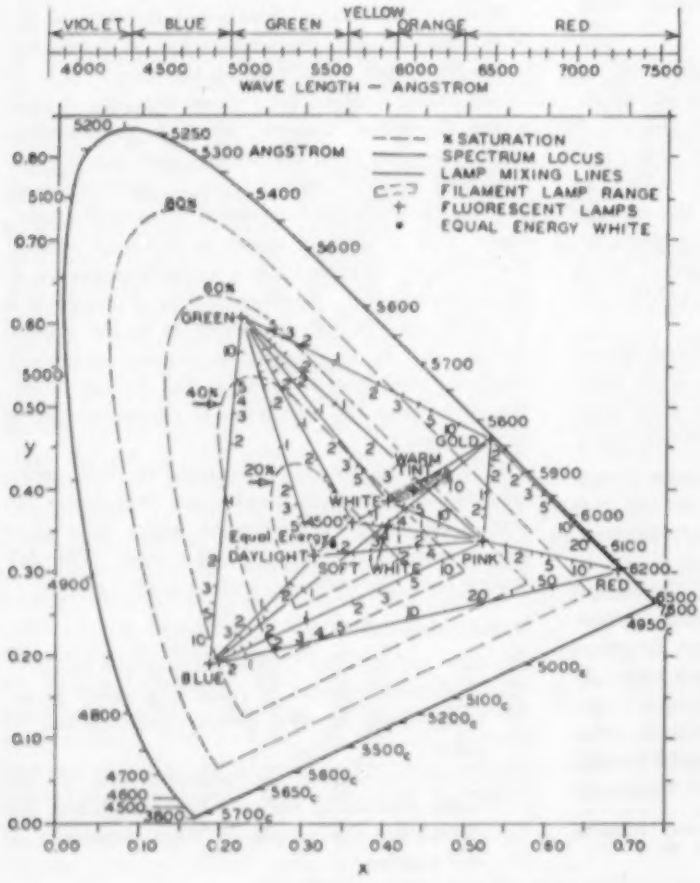
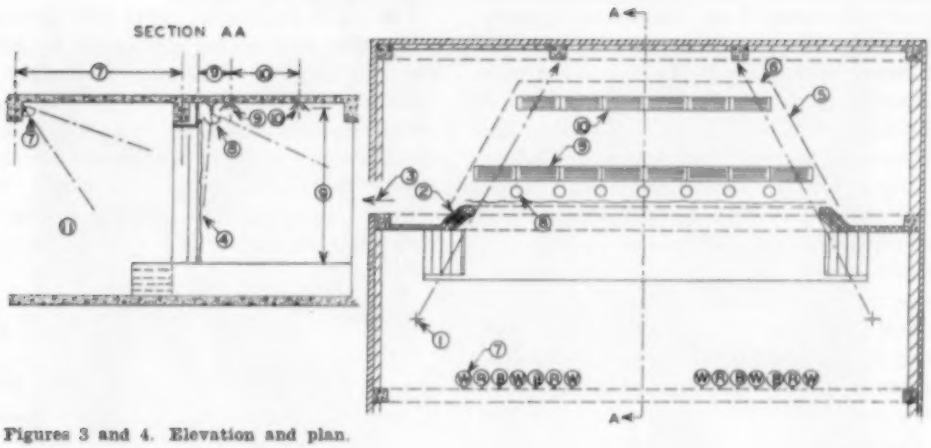


Figure 1. Visible portion of spectrum.

Figure 2. Color mixture nomograph. (Based on similar diagrams, pages 46-47, "Fundamentals of Light and Lighting," Walter Sturrock and Karl A. Staley.)



Figures 3 and 4. Elevation and plan.

1. End seat.
2. Lighting panel.
3. To dressing rooms.
4. Front curtain.
5. Side curtains.
6. Rear curtain.
7. Front floods and spots — consist of 3 white floods, 2 red and 2 blue spots with 150-watt PAR-38 reflector lamps on each side of proscenium. Shall be concealed behind ceiling beam and be protected from mechanical injury if room is to be used for combination gymnasium and auditorium.
8. Stage spots — consist of 5 to 7 white 150-watt PAR-38 reflector spot lamps depending on width of proscenium opening. Spots shall be installed immediately after proscenium opening after allowing space for front curtain.
9. First stage border — consists of 6, 8 or 10 4-lamp 40-watt colored fluorescent fixtures, or sets of two 2-lamp units gang mounted as shown in Fig. 5. Arrangement and connection of lamps shall be as described on schedule. Border shall be located not more than 3 feet from the back of proscenium and shall be kept as high as possible to have minimum 12-foot clearance from stage floor to assure proper color mixing. Fixtures may either be mounted on ceiling slab or on lowerable devices.
10. Second stage border — consists of two less fixtures than first border. Maximum spacing between two borders shall not be more than 6 to 8 feet. If stage is not deep enough to require second border, first border shall be moved back to the 1/3 point of the stage.
11. General illumination for house area is not shown.

TABLE I.—Lamp and Circuit Arrangements.

Border No.	Lamp No.	Col.	Cir.	Col.	Cir.	Col.	Cir.	Col.	Cir.	Col.	Cir.	Col.	Cir.	Col.	Cir.	Col.	Cir.
								Fixture No.									
				1		2		3		4		5		6		8	
	a			G	1	Y	2	G	1	Y	2	G	1	Y	2		
Second	b			Y	2	B	3	Y	2	B	3	Y	2	B	3		
Border	c			R	4	Y	2	R	4	R	2	R	4	Y	2		
	d			G	1	R	4	G	1	G	4	G	1	R	4		
								Fixture No.									
		1		2		3		4		5		6		7			
	a	G	1	Y	2	G	1	Y	2	G	1	Y	2	G	1	Y	2
First	b	Y	2	B	3	Y	2	B	3	Y	2	B	3	Y	2	B	3
Border	c	R	4	Y	2	R	4	Y	2	R	4	Y	2	R	4	Y	2
	d	G	1	R	4	G	1	R	4	G	1	R	4	G	1	R	4

Col. — Color of Lamp: Based on standard T12 40-watt lamps. See Fig. 2.
Y — Gold (yellow); B — Blue; G — Green; R — Red.
Cir. — Circuit number.
NOTE: (1) Each border consists of a continuous row of two 2-40w standard industrial fixtures as shown in Fig. 5b or one 4-40w open bottom fixture as shown in Fig. 5a.
(2) Number of fixtures in each border shall be multiple of 2, or even number.
(3) When odd number of colored lamps is required, one single lamp ballast for each color concerned shall be used.

TABLE II.—Mixture of Colors.

Mixture of	Ratio	Color of Mixture	Predominant Wavelength, °A	% Saturation
B-G	1:2	Blue-Green	5050	35
B-R	1:2	Light Violet	4500	38
B-Y	1:3	Soft White	5930	20
G-Y	2:3	Light Yellow	5600	70
R-Y	2:3	Amber	5870	98

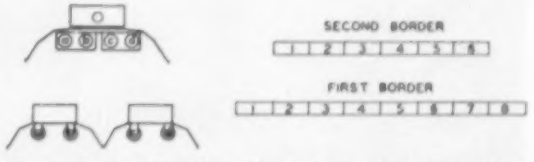


Figure 5. Border and lamp numbers. Four-lamp unit is shown at left top, and alternate two-lamp unit below.

factory. Actual testing of one installation recently completed is the Windsor Elementary School. An excellent mixture of warm white is observed with the combination of gold and blue circuits at a level above 70 footcandles. Other color combinations are also uniform and pleasant. Of course, one of the determining factors of this selection is the "cost." In general, the cost of fluorescent border as indicated is comparable to that of incandescent border, but provides much higher intensity of illumination, more color combinations, less wattage, and lower radiant heat. Therefore, it will ultimately result in a saving in cost and flexibility in color combination. As has been mentioned previously, this is not a complete replacement of the conventional incandescent borders, as many of the advantages of incandescent systems are essentials in high school drama and theatrical productions which cannot be achieved by fluorescent borders.

The use of fluorescent lights does, however, open a new field with limited application for economical stage lighting in small and elementary schools. Incidentally, the mixing of colored fluorescent lamps may also be applied with advantage for general illumination in show windows for stores and many other commercial installations. However, detailed discussion of such subjects is beyond the scope of this paper.

Notes

1. *IES Lighting Handbook*, Second Edition, p. 11-20 (1952).
2. *The Lighting Engineer*, Lamp Division, General Electric Co., Vol. III, No. 1 (February 1955).
3. Davis, A., Stephenson, R. E., and Harris, L. D.: "A New Low-Cost Dimmer for Hot Cathode Fluorescent Lamps," ILLUMINATING ENGINEERING, Vol. L, No. 3, p. 143 (March 1955).
4. Based on similar diagrams on p. 46-47, "Fundamentals of Light and Lighting," Walter Sturrock and Karl A. Staley, General Electric Co.
5. The arrangement of lamps as shown is intended for a perfect mixture of colors at working level 5-6 feet above the floor. If stage ceiling is above 10 feet, a simpler manner of lamp arrangement to have same color lamps in row or rows may be used. Two 2-lamp 40-watt fixtures may be used instead of 4-lamp fixtures.

Lighting the Streets of Cairo

An especially designed street lighting luminaire, using four 40-watt rapid start fluorescent lamps, is in use for lighting the streets of Cairo, Egypt. The unit consists of a roof-shaped reflector, 21 inches wide by 50 inches long; a weatherproof wiring channel hood containing two dual ballasts and a dust-tight cover of ribbed diffusing plexiglas, ⅛-inch thick. The luminaire was designed to hold five 40-watt lamps, but in this installation is equipped with only four—standard cool white, 2400-lumen, mounted as shown in the diagram. Economy dictated the use of existing poles from the previous installation, although considered inadequate.

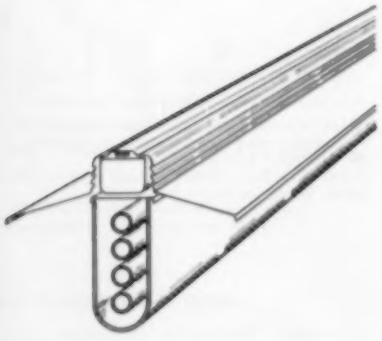


Photo and data courtesy of Fluorescent Lighting Company Cairo, Egypt.

A.I.A. File No. 31

INSTALLATION IN EAST ORANGE, NEW JERSEY.

Luminous Ceiling in a Remodeled Bathroom

LIGHTING OBJECTIVE: To provide general lighting and local illumination at the mirror in a small bathroom by means of a complete ceiling of light.

GENERAL INFORMATION: This 5' 2" by 7' 4" bathroom in an old apartment building has a 9-foot ceiling, white tile floor, and white tile walls up to four feet (7½ feet around tub) with 45 per cent average reflectance wallpaper above the tile.

INSTALLATION: Fig. 2 shows the details of installation of the corrugated translucent plastic (Luminous Ceilings, Inc., Chicago) with 50 per cent transmission factor, mounted below five 40-watt deluxe warm white instant start fluorescent lamps. The inside of the cavity above the plastic is painted a flat white. Footcandle readings were taken in approximately the positions specified by the I.E.S. (See drawing on Page 18, Recommended Practice for Residence Lighting.)

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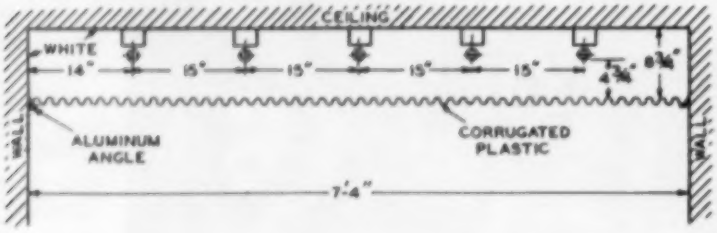

Figure 2. Installation details.

This system provides the following levels of illumination after nine months in service:

On nose	40 footcandles
On cheek	40 footcandles
Under chin	35 footcandles
Top of forehead	70 footcandles
Top of head (horizontal)	120 footcandles
Average on 30" plane	55 footcandles

The maximum ceiling brightness (directly beneath lamps) is 250 footlamberts, and minimum (between lamps) is 140 footlamberts. This variation (about twice that recommended for large commercial areas) is scarcely noticeable in this small area of approximately 36 square feet.

Lighting data submitted by Miss Myrtle Fahsbender, Director of Residential Lighting, Westinghouse Lamp Division, Bloomfield, New Jersey as one solution to a lighting problem and to aid in the design of similar installations.

Published by the Committee on Publications of the Illuminating Engineering Society, 1860 Broadway, New York 23, New York.

Brightness and Illumination By Interreflections in Enclosures

By ROBERT SWERN WISEMAN

THE PURPOSE of this research was to assimilate the ideas and concepts of enclosure theory in concrete form and to verify the results experimentally. Beginning with the most fundamental concepts, equations were developed to predict the illumination on horizontal planes (work surfaces) and the luminous emittances of the walls, ceiling and floor. A model room was constructed, and values were obtained for the room dimensions, reflection factors, initial and final surface luminous emittances, and illumination. The final luminous emittance and illumination values were calculated by using the derived equations, and these calculated values were compared with the measured values. As a result of these comparisons, it may be determined that the theoretical equations predict the final results with sufficient accuracy for most applications, but to satisfy more exacting requirements, "correction factors" were calculated which when applied to the derived equations reduced the variations between the calculated and measured values to less than five per cent for most comparisons of practical importance.

Theoretical Development

The theoretical development accomplished in this research paralleled the work performed by Moon and Spencer; however, the development began with the basic principles and is complete in itself. All equations were derived independently, and the final equations were compared with those published by Moon and Spencer.[1,2] Differences were found between two of the published equations and the derived equations, and calculations for a sample problem indicated that the values calculated by using the derived equations are the same as recorded in the published tables.[1,2,3,4]

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 13-17, 1954, Atlantic City, New Jersey. Abstract of a thesis which was submitted as partial fulfillment of the requirements for the degree of Doctor of Philosophy in Electrical Engineering while enrolled in the Graduate College, University of Illinois, Urbana, Ill. AUTHOR: Presently, Chief, Research and Photometric Section, Night Vision Equipment Branch, Electrical Engineering Department, Engineer Research and Development Laboratories, Fort Belvoir, Va.

Definitions of Symbols and Terms

The following are the definitions of symbols and terms which have been used in this research.

1 = reference number for wall surfaces.

2 = reference number for ceiling surface.

3 = reference number for floor surface.

E = illumination. Defined as the density of luminous flux incident upon a surface. The unit of illumination is the footcandle (ft-c).

$E_1(s)$ = average illumination on walls at a distance s from the ceiling.

E_2 = average illumination on the ceiling.

E_3 = average illumination on the floor.

$E(h)$ = average "interreflected illumination" on the top of a horizontal plane located a distance h from the ceiling. The "interreflected illumination" is caused by luminous flux interreflected from the surfaces and is not caused by any flux directed from the luminaires direct to the horizontal surface.

E_D = average "direct illumination" on the top of a horizontal plane located a distance h from the ceiling. The "direct illumination" is caused only by the direct flux from the luminaires direct to the horizontal plane. If there are no luminaires but only self-luminous surfaces as the sources of light, the direct illumination will be zero.

f = interflectance factor. Ratio of the number of lumens incident on a horizontal plane to the lumens emitted by the source. The

source is the luminaire if the enclosure surfaces have initial luminous emittance because of reflected light; and if the surfaces are self-luminous, the surfaces are considered as the source. This factor is the same as the "utilization factor" which is used in the Lumen Method of illumination design.

f_1 = interflectance factor for wall lighting. $L_{o1} \neq 0$, $L_{o2} = 0$, and $L_{o3} = 0$.

f_2 = interflectance factor for ceiling lighting. $L_{o1} = 0$, $L_{o2} \neq 0$, and $L_{o3} = 0$.

f_3 = interflectance factor for floor lighting. $L_{o1} = 0$, $L_{o2} = 0$, and $L_{o3} \neq 0$. The direct light from the luminaires to the horizontal plane for which the interflectance factor is being calculated is not considered as a component of f_3.

f_D = interflectance factor for direct light from luminaires to the horizontal plane. If there are no luminaires but only self-luminous surfaces, the value of f_D is zero.

L = luminous emittance. Defined as the total number of lumens emitted divided by the area which emitted the lumens. This unit of luminous emittance is the footlambert (ft-L). This term is sometimes called brightness and given the symbol B'. The proposed international symbol is H. The symbol L has been used by several authors and has been chosen as the symbol for luminous emittance in this thesis.

$L_1(s)$ = average final luminous emittance of the wall at a distance s from the ceiling.

L_2 = average final luminous emittance of the ceiling.

L_3 = average final luminous emittance of the floor.

L_0 = initial luminous emittance caused by the first reflection of the luminous flux directed from luminaires to the surface or by the transmission of luminous flux from the cavity behind the surface.

L_{o1} = average initial luminous emittance of the wall.

L_{o2} = average initial luminous emittance of the ceiling

L_{o3} = average initial luminous emittance of the floor.

$\rho_1(s)$ = average wall reflection factor at a distance s from the ceiling.

ρ_2 = average ceiling reflection factor.

ρ_3 = average floor reflection factor.

p = perimeter of the horizontal cross section of enclosure.

S = area of the horizontal cross section.

l = ceiling height of enclosure.

w_1, w_2 = dimensions of rectangular cross section.

k_r = room index.

kernel = integrand of the integral equation which expressed the illumination on a surface.

Development of Theoretical Equations

The following premises were formulated in establishing the fundamental problem and to simplify the resulting equations so that usable equations could be obtained.

I. All surfaces are perfectly diffusing, and each surface has a uniform reflection factor (all four walls are considered as only one surface). No surface has a reflection factor greater than or equal to unity.

II. The medium within the enclosure is transparent and nondissipative.

III. The initial luminous emittances of each surface are uniform.

IV. The final luminous emittances of the ceiling and floor are each uniform and the final luminous emittance of the wall is dependent only on the distance from the ceiling and is independent of the location around the wall.

V. The kernel of the integral equation can be approximated by an exponential function.

The resulting general equations express the final values of illumination and luminous emittance as functions of the enclosure dimensions (k_r); wall, ceiling and floor reflection factors; and initial luminous emittances of wall, ceiling and floor. Since the initial luminous emittance terms appear independent of each other, the general equations may be replaced by component equations. The component equations for wall, ceiling and floor lighting were obtained by assuming the initial luminous emittances of all surfaces equal to zero except the surface named. The values of final luminous emittance and illumination calculated for each component system may be combined to determine the total values of final luminous emittance and illumination.

The following summarizes the equations derived in this research for the three component system.

EQUATIONS APPLICABLE TO ALL COMPONENTS

$$k_r = \frac{w_1 + w_2}{2\, w_1\, w_2}\, l$$

$$G = \{[2(1+\rho_2\rho_3) - \rho_1(1+\rho_2)(1+\rho_3)]\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + 2(1-\rho_1)^{\frac{1}{2}}(1-\rho_2\rho_3)\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r\}^{-1}$$

Wall Lighting

$$L_{01} \neq 0 \qquad L_{02} = 0 \qquad L_{03} = 0$$

$$E(h) = \frac{L_{01}}{1-\rho_1} + \frac{L_{01}G}{1-\rho_1}\Big\{ [2(1-\rho_1)^{\frac{1}{2}}(1-\rho_2)\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_2)[2-\rho_1(1+\rho_3)]\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_3)[2\rho_2-\rho_1(1+\rho_2)]]\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r(h/l) - [(1-\rho_2)[2-\rho_1(1+\rho_3)]\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + 2(1-\rho_1)^{\frac{1}{2}}(1-\rho_2)\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r + 2\rho_2(1-\rho_1)^{\frac{1}{2}}(1-\rho_3)]\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r(h/l)\Big\}$$

$$B_1 = \frac{-\rho_1 G L_{01}}{1-\rho_1}[(1-\rho_2)(1-\rho_3)\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_1)^{\frac{1}{2}}(1-\rho_2)(1+\rho_3)\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_1)^{\frac{1}{2}}(1+\rho_2)(1-\rho_3)]$$

$$C_1 = \frac{\rho_1(1-\rho_2)GL_{01}}{1-\rho_1}[(1-\rho_3)\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_1)^{\frac{1}{2}}(1+\rho_3)\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r - (1-\rho_3)]$$

$$D_1 = \frac{L_{01}}{1-\rho_1}$$

$$L_1(s) = B_1\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r(s/l) + C_1\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r(s/l) + D_1$$

$$L_2 = \frac{2\rho_2(1-\rho_1)^{\frac{1}{2}}}{\rho_1(1-\rho_2)}C_1$$

$$L_3 = \frac{2\rho_3 G L_{01}}{1-\rho_1}[(1-\rho_1)(1+\rho_2)\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_1)^{\frac{1}{2}}(1-\rho_2)\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r - (1-\rho_1)^{\frac{1}{2}}(1-\rho_2)]$$

(The preceding equation for $E(h)$ is the first of two which are in disagreement with the equations published by Moon and Spencer.[1] This equation differs in the coefficient of $\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r(h/l)$. The coefficient in the published equation[1] is

$$[2\rho_3(1-\rho_1)^{\frac{1}{2}}(1-\rho_2)\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r - (1-\rho_2)[2\rho_3-\rho_1(1+\rho_3)]\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_3)[2\rho_2-\rho_1(1+\rho_2)]]$$

The value calculated for a sample problem by using the equation derived in this research agrees with the values obtained by using the general equation for $E(h)$, before reduction to component equations, and by referring to published tables.[1,2] The value calculated by using the published equation[1] does not agree with the calculated or tabular value.)

Ceiling Lighting

$$L_{01} = 0 \qquad L_{02} \neq 0 \qquad L_{03} = 0$$

$$E(h) = L_2\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r(h/l) - L_{02}G[2(1-\rho_1)^{\frac{1}{2}}\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + [2-\rho_1(1+\rho_3)]\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r]\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r(h/l)$$

$$B_2 = \rho_1 L_{02}G[(1-\rho_3)\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_1)^{\frac{1}{2}}(1+\rho_3)\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r]$$

$$C_2 = -\rho_1 L_{02}G[(1-\rho_3)\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r + (1-\rho_1)^{\frac{1}{2}}(1+\rho_3)\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r]$$

$$D_2 = 0$$

$$L_1(s) = B_2\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r(s/l) + C_2\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r(s/l)$$

$$L_2 = L_{02}G[[2-\rho_1(1+\rho_3)]\sinh 2(1-\rho_1)^{\frac{1}{2}}k_r + 2(1-\rho_1)^{\frac{1}{2}}\cosh 2(1-\rho_1)^{\frac{1}{2}}k_r]$$

$$L_3 = 2\rho_3 L_{02}G(1-\rho_1)^{\frac{1}{2}}$$

$$L_{o1} = 0 \qquad L_{o2} = 0 \qquad L_{o3} \neq 0$$

$$E(h) = L_{o3}\, G \left[[-2\rho_2 + \rho_1(1+\rho_2)] \sinh 2(1-\rho_1)^{\frac{1}{2}} k_r (h/l) + 2\rho_2 (1-\rho_1)^{\frac{1}{2}} \cosh 2(1-\rho_1)^{\frac{1}{2}} k_r (h/l) \right]$$

$$L_{i1}(s) = B_3 \cosh 2(1-\rho_1)^{\frac{1}{2}} k_r (s/l) + C_3 \sinh 2(1-\rho_1)^{\frac{1}{2}} k_r (s/l)$$

$$B_3 = \rho_1 (1-\rho_1)^{\frac{1}{2}} (1+\rho_2) G L_{o3}$$

$$C_3 = \rho_1 (1-\rho_2)\, G L_{o3}$$

$$D_3 = 0$$

$$L_2 = 2\rho_2 (1-\rho_1)^{\frac{1}{2}} G L_{o3}$$

$$L_3 = L_{o3} G \left[2(1-\rho_1)^{\frac{1}{2}} \cosh 2(1-\rho_1)^{\frac{1}{2}} k_r + [2-\rho_1(1+\rho_2)] \sinh 2(1-\rho_1)^{\frac{1}{2}} k_r \right]$$

(The preceding equation for L_3 is the other derived equation that disagrees with the previously published equation.[1] The differences are in the coefficient of $\sinh 2(1-\rho_1)^{\frac{1}{2}} k_r$. The published coefficient is $(2-\rho_1)(1+\rho_2)$. Again, the value calculated by the derived equation is the same as the published tabular values[1,3] whereas the value calculated by the published equation does not agree with the tabular value.)

In addition to these equations a quantity called the "interflectance factor," similar to the utilization factor, has been defined. Basically, the interflectance is the ratio of the luminous flux incident on the horizontal plane (work surface) to the luminous flux emitted by the luminaires. When expressed as component interflectance factors, the definition is the ratio of the luminous flux to the work surface for each component independently to the luminous flux emitted by the luminaires toward the component surface if not self-luminous or emitted by the component surface if self-luminous.

The following ratios are the component interflectance factors for surfaces that are luminous because of reflected light.

$$f_1 = \frac{\rho_1}{4k_r} \frac{E(h)}{L_{o1}}$$

$$f_2 = \rho_2 \frac{E(h)}{L_{o2}}$$

$$f_3 = \rho_3 \frac{E(h)}{L_{o3}}$$

The total interflectance factor is the weighted average of these component interflectance values.

$$f_T = \frac{F_1 f_1 + F_2 f_2 + F_3 f_3 + F_D}{F_1 + F_2 + F_3}$$

(It should be noted that the floor interflectance, f_3, is defined differently than previously defined by Moon and Spencer. Previously, the direct flux had been included in the floor interflectance by considering the direct flux as only that flux directed towards the floor and adding it to the interreflected flux expressed as $E(h)$. This neglects that portion of the flux directed toward the lower part of the walls which also is directed towards the work surface. By considering the direct flux as a separate quantity, the error caused by the omission of this flux directed through the work surface toward the walls will be eliminated.)

If the surfaces are self-luminous, the surfaces themselves are considered as the luminaires and the following definitions apply.

$$f_1 = \frac{1}{4k_r} \frac{E(h)}{L_{o1}}$$

$$f_2 = \frac{E(h)}{L_{o2}}$$

$$f_3 = \frac{E(h)}{L_{o3}}$$

$$f_T = \frac{F_1 f_1 + F_2 f_2 + F_3 f_3}{F_1 + F_2 + F_3}$$

Method of Reporting Data

Two methods of reporting data calculated from the theoretical equations have been proposed. One is to use the ratios of the final luminous emittances and illumination to the initial luminous emittances, and the other is to use the ratios of the final luminous emittances to the illumination on the work surface and to include the interflectance factor so the illumination may be calculated. Each of the two methods has its advantages and disadvantages, and for this reason, the experimental data are compared with the values obtained for both methods.

Justification for the Use of a Model Room

The performance of a prototype may be predicted from a model provided that they behave similarly qualitatively and that a qualitative relationship may be established between them. A geometrically similar model was used in this research.

The illumination properties and variables in design are:

L — luminous emittance of reference source — lumens/sq. ft.

L_i — luminous emittances of other sources — lumens/sq. ft.

l — reference length—ft.

l_i — other lengths—ft.

E — illumination on a surface—lumens/sq. ft.
ρ — reflection factor of surfaces—per cent

The above six quantities are expressed in only two units, lumens and feet; therefore, only four Pi terms are required. One possible group is as follows:

$$\frac{E}{L} = f\left(\frac{l_i}{l}, \rho, \frac{L}{L_i}\right)$$

The three corresponding design equations for a model that would be a true model are as follows. The subscript m refers to the quantities measured in the model. From geometric symmetry:

$$\frac{l_{im}}{l_m} = \frac{l_i}{l}$$

$$l_{im} = l_i\left(\frac{l_m}{l}\right) = \frac{l_i}{n}$$

From reflectance similarity:

$$\rho_m = \rho$$

From equal relative luminous emittances:

$$\frac{L_m}{L_{im}} = \frac{L}{L_i}$$

The prediction equation then follows.

$$\frac{E_m}{L_m} = \frac{E}{L}$$

$$E = \frac{L}{L_m} E_m$$

If, in addition, L_m is considered equal to L, then E is equal to E_m, and the ratio $\frac{E}{L}$ is the same as $\frac{E_m}{L_m}$. This shows that a true geometrically similar model with reflectance similar and equal relative luminous emittances may be used to predict the results of a design.

Experimental Development

An experimental room, Fig. 1, was constructed so that its properties would approximate the premises made in the theoretical development.

The room had a square cross-section, six feet on a side, and the floor was made movable so that a range of room indices, k_r-values, could be obtained. The walls and ceiling were made of sandblasted, white-translucent Plexiglas, one-eighth inch thick, and the floor was made of plywood which was painted a flat gray of approximately thirty per cent reflectance.

The translucent walls and ceiling were illuminated independently from cavities located outside of the enclosure so that the initial luminous emittance of each could be adjusted to any desired value, Fig. 2. The cavity depth was eighteen inches and the back surface of the cavity was nine feet

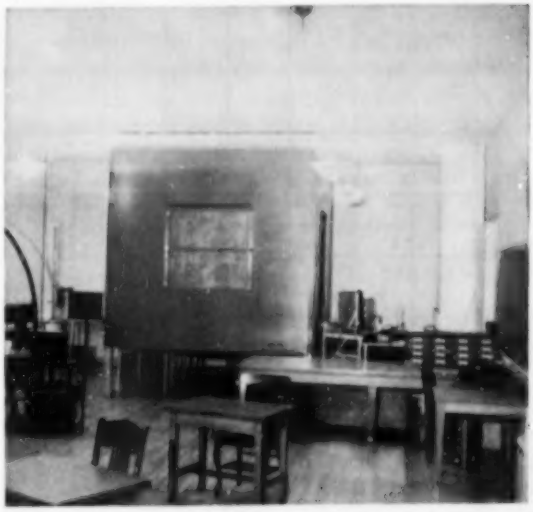

Figure 1. View of experimental room as seen from the South. Six-foot cubical Plexiglas room with movable floor enclosed by nine-foot-square plywood surfaces.

square. Wooden baffles, which subtended angles of 135 degrees with the walls, separated the ceiling and wall cavities and closed off the bottom of the wall cavity. The wall cavity was continuous around the exterior of the enclosure. All surfaces inside the cavity except the Plexiglas were painted a flat white of approximately 85 per cent reflection factor.

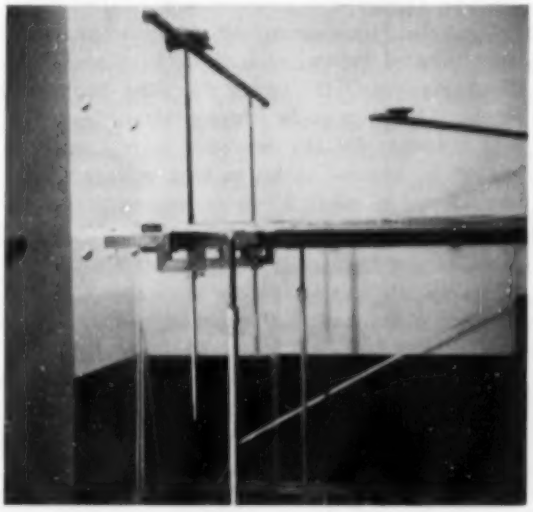

Figure 2. View of experimental room during construction with West plywood door opened and North and West Plexiglas walls removed. Horizontal track used for positioning cells to obtain wall data is shown on left and sweep arm for positioning cells to obtain data for horizontal surfaces is shown on the right. Silver-bowl incandescent lamps are shown mounted on the plywood walls.

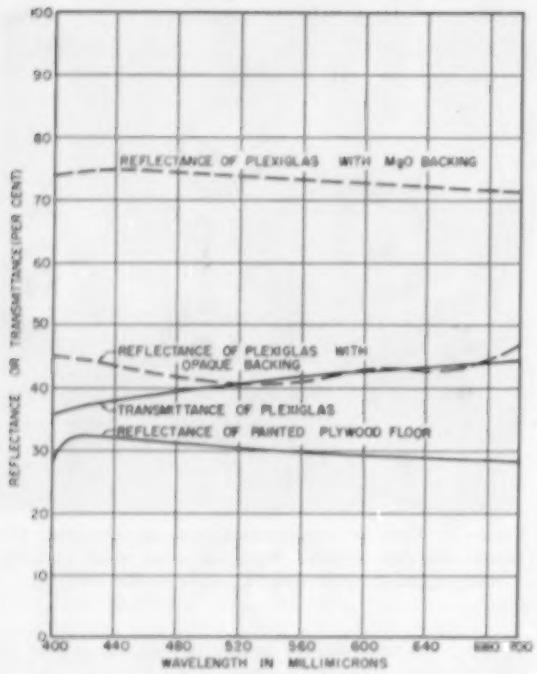
REFLECTANCE OF PLEXIGLAS WITH MgO BACKING
REFLECTANCE OF PLEXIGLAS WITH OPAQUE BACKING
TRANSMITTANCE OF PLEXIGLAS
REFLECTANCE OF PAINTED PLYWOOD FLOOR
REFLECTANCE OR TRANSMITTANCE (PER CENT)
WAVELENGTH IN MILLIMICRONS

Figure 3. Reflectance and transmittance curves of ⅛-inch thick Plexiglas with one side sandblasted, and reflectance of painted plywood floor.

Silver-bowl incandescent lamps (100-watt - 120-volt) were mounted on twenty-four inch centers on the cavity backs so that the light was directed to the outer surface of the cabinet and diffused before striking the Plexiglas surface. There were sixteen lamps located behind each six-foot square Plexiglas surface, and the power for these lamps was obtained from an ac-dc motor-generator set. The field rheostats for the generator were located on one of the control tables so that voltage adjustments could be made whenever necessary.

In order to maintain constant lighting conditions, barrier layer cells were mounted in the ceiling and wall cavities, and the field rheostats were adjusted so that the readings on the microammeters connected to these cells remained constant throughout each test. In addition to this check on constant conditions, a voltmeter was also used for reference.

Data were taken with the walls as the only source of light and with the ceiling as the only source. Two sets of data were obtained with ceiling lighting, the first with the walls backed by the cavities as described (approximately 70 per cent reflection factor), and the second with the walls backed with opaque material which reduced the wall reflection factor to approximately 55 per cent.

All reflection factors were measured with the surfaces in the enclosure, and the effects of the location of the area with respect to the other surfaces are included. Since the reflection factor is defined as the ratio of the light reflected by the body to the incident light, the reflection factor was determined by measuring the luminous emittance of an area (lumens emitted per unit area) and the illumination on the same area (lumens incident per unit area). The ratio of the luminous emittance to the illumination is the reflection factor for each area.

Compliance with Basic Premises

Premise I assumes that all surfaces are perfectly diffusing and each surface should have a uniform reflection factor. It was determined experimentally that the white-translucent Plexiglas with spectral reflection and transmission characteristics shown in Fig. 3 was the best material available. By sandblasting one surface of the Plexiglas, the diffusion characteristics were transformed as shown in Fig. 4 and the first requirement was satisfied. The floor was painted with a paint obtained by thoroughly mixing a bone black with a flat white paint until the spectral characteristics were as shown in Fig. 3.

Compliance with the second part of the first premise was not as easy as may first be assumed for the following reasons. There seems to be no

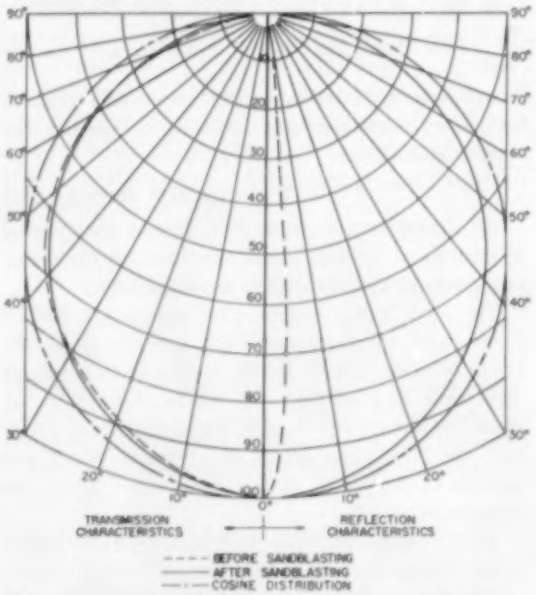

Figure 4. Diffusion characteristics of ⅛-inch thick Plexiglas before and after sandblasting one surface. Data are plotted in per cent of the intensity in the zero degree direction (normal to the sandblasted surface).

reliable method of measuring reflection factors, and the effect of the location of the area with respect to other surfaces must be considered. In order to better satisfy the uniformity requirements, the wall cavity was made continuous around the outside of the walls. Reflection factors were calculated from measured luminous emittance and illumination data and the following table shows the variations present in the wall reflection factors.

Variation of Wall Reflection Factor Expressed in Per Cent of Average.

Cavity Backing	k_r		
	0.993	0.743	0.520
top	−8%	−6%	−3%
bottom	+8	+4	+4
corner	−1	−0.4	−0.7
one-fifth of wall width from corner	+0.4	+0.6	+0.7
Opaque Backing			
top	−0.2	+0.2	−0.2
middle	−0.4	−2.2	−2.0
bottom	+2.5	+2.3	−0.4
corner	−2.3	−2.5	−3.0
one-fifth of wall width from corner	+2.0	+1.9	+0.9

The ceiling reflection factor varied from +5.5 per cent in the center to −3.5 per cent near the walls. The floor reflection factor varied from about −2 per cent in the center to +5 per cent near the walls.

The securing of surfaces with only the small variations indicated is acceptable when the confusion regarding reflection factors is considered and when it is realized that in an actual application the presence of doors, windows, trim, and furnishings along the wall will certainly result in a much wider variation of reflection factors.

Premise II, which requires the medium within the enclosure to be transparent and nondissipative, must be violated in order to take any measurements. The following precautions were taken in order to best approximate the desired conditions. Both cells for measuring the illumination and luminous emittance were made as small as practicable and all surfaces that did not contribute to the cell response were painted a flat white of approximately 85 per cent reflectance. All mechanisms used to hold or locate the cell were made as small as practicable and were either painted flat white or were sheathed with white flannel.

Premise III requires the initial luminous emittances of each surface to be uniform. To achieve this condition, cavity lighting was used and tests were conducted to obtain the best practical cavity depth and lamp spacing. The initial ceiling luminous emittance varied from about −2.7 per cent at the center of the room to +1.0 per cent near the walls, and the initial luminous emittance of the walls when they were the source varied as shown in the following table.

Variations of Initial Luminous Emittance of Wall Surface With Cavity Backing Expressed in Per Cent of Average.

	k_r		
	0.993	0.743	0.520
top	+13%	+10%	+6%
bottom	−13	−7	−8
corner	+5.4	+4.1	+4.8
center	−2.2	−2.6	−2.4

The values of initial wall luminous emittance for the wall surface were calculated in the following manner. Data were obtained of the wall luminous emittance and illumination on the wall with the ceiling as the only source of light. Reflection factors of the various wall areas (84 measured areas) were calculated by dividing the luminous emittance value by the respective illumination value. With the walls as the source, data were again taken of the wall luminous emittance and illumination on the wall caused by interreflected light. These values of wall illumination were multiplied by the wall reflection factor calculated for the same location, and this product, which is the luminous emittance component caused by interreflected light, was subtracted from the measured luminous emittance at that location to obtain the initial wall luminous emittance. If the wall is assumed to have a uniform reflection factor, the variation of the initial luminous emittance is decreased to within ±5 per cent.

Since there will seldom if ever be any actual installation in which the entire wall surface will have a uniform initial luminous emittance with variations as small as ±15 per cent, the walls by comparison, may be said to have practically a uniform initial luminous emittance.

Premise IV assumes that the final luminous emittances of the ceiling and floor are uniform and that the final luminous emittance of the wall is dependent only on the distance from the ceiling and is independent of the location around the wall.

These conditions cannot be built into a room but are conditions that may or may not exist. The measured data indicate that these conditions are approximated in the model room. The variation of the final luminous emittance of the ceiling was within +1.5 per cent to −4 per cent when the ceiling was the only source of light and within ±7 per cent when the walls were the source.

The variations of the final luminous emittance of floor were as shown in the following table.

Variation of Final Luminous Emittance of the Floor Expressed in Per Cent of Average for Both Opaque and Cavity Backing of Walls.

	k_r		
Ceiling Lighting	0.993	0.743	0.520
maximum	+8%	+13%	+15%
minimum	−4	−8	−10
Wall Lighting			
maximum	+1.4	+1.1	+2.0
minimum	−1.3	−0.8	−2.5

The average variations of the final luminous emittance around the wall were shown as follows:

Variation of Final Luminous Emittance Around Wall Expressed in Per Cent of Average.

Ceiling Lighting		k_r 0.993	0.743	0.520
Cavity Backing	corner	−7%	−8%	−9%
	center	+4	+5	+4
Opaque Backing	corner	−10	−11	−12
	center	+5	+5	+5
Wall Lighting				
Cavity Backing	corner	+4	+6	+7
	center	−3	−3	−5

The dependency of the final wall luminous emittance on the distance from the ceiling is shown in the comparisons of the calculated and experimental data. The data show that the theoretical and experimental variations of final wall luminous emittance with respect to the distance from the ceiling are practically the same.

Premise V which states that the kernel of the integral equation can be approximated by an exponential function assumes conditions which, like those of Premise IV, cannot be built into the experimental room, and justification for making this assumption must be based on the precision with which the illumination and luminous emittance values may be predicted.

Methods of Measurement

Illumination measurements were obtained by using a cell assemblage which was developed for this research and called the E-cell, Fig. 5. A circular barrier layer cell with color-correcting filter was used as the basic element and this cell was fitted with a clear plastic dome which had a one-inch spherical radius. The interior surface of the dome was sandblasted and a small masking spot was attached to the top to further correct the angular response. A black, 18-degree flare, five inches in diameter, was attached to shield the dome from light incident at angles greater than 90 degrees. The use of these attachments changed the

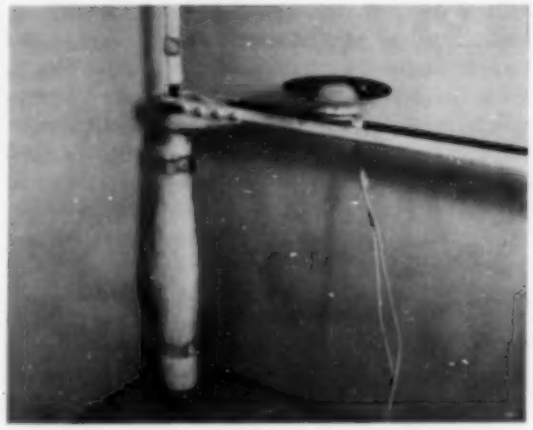

Figure 5. Sweep arm used for positioning cells to obtain data for horizontal surfaces is shown with cell, adapted with flare and dome for measuring the illumination, mounted on carrier.

angular response of the cell as shown in Table 1, and the cell remained color corrected because of the uniform spectral transmission of the dome.

The E-cell was calibrated on a bar photometer before and after the measurements were made, and good photometric practice was used throughout the tests to obtain the most accurate results.

A second barrier layer cell was also developed so that the luminous emittance readings could be obtained more readily and accurately than by using visual brightness meters. The basic cell was a color-corrected barrier layer cell, and it was mounted in one end of a metal cylinder with a lens mounted in

TABLE 1.—Angular response of uncorrected cell and corrected cell with assemblage of the uncorrected cell, plastic dome, and shielding flare. Data are recorded as per cent of reading obtained with light incident normal to the face of the cell (zero degree).

Angle of Incidence in Degrees	Response of cell in per cent* Uncorrected Cell	Corrected Cell	Cosine Response (per cent)
0°	100.0	100.0	100.0
5	——	100.0	99.6
10	97.5	98.5	98.5
15	——	97.3	96.6
20	91.0	94.7	94.0
25	——	91.4	90.6
30	81.0	87.2	86.6
35	——	83.3	81.9
40	68.7	77.1	76.6
45	——	71.3	70.7
50	51.7	63.8	64.3
55	——	57.0	57.4
60	35.0	49.9	50.0
65	——	41.7	42.3
70	16.5	33.8	34.2
75	——	25.0	25.9
80	2.0	14.6	17.4
85	——	7.1	8.7
90	0.0	2.0	0.0
92.3	0.0	0.0	0.0

*Response expressed in per cent of reading obtained with light incident at zero degree, and the recorded value is the average obtained by rotating the cell.

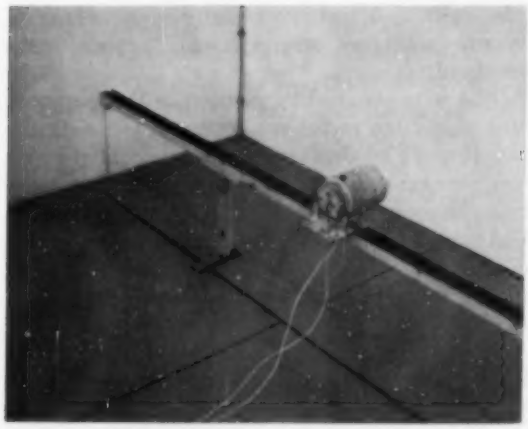

Figure 6. Horizontal track with cell, adapted to measure luminous emittance, is shown in a position to measure luminous emittance of the wall.

the other end, Figs. 6, 7 and 8. The interior of the cylinder was painted flat black to eliminate interreflections. When the face of the basic cell was about fourteen inches from and parallel to a surface, a circular area approximately five inches in diameter was imaged on the sensitive area of the cell face. This assemblage, called the L-cell, was calibrated by locating it in the model room just as it was to be used and obtaining current readings as the luminous emittance of the measured surface varied over the required range. At each setting of the luminous emittance, simultaneous luminous emittance values were obtained by taking a series of readings with a Luckiesh-Taylor brightness meter carefully calibrated for this particular investigation. A calibration curve for the L-cell was obtained by relating the current reading with the average of the luminous emittance values obtained with the brightness meter for each setting. Since there was only a small amount of light incident on the cell, it was necessary to use a potentiometer type microammeter equipped with a galvanometer to obtain accurate readings. The meter had ranges of 0.5, 1, 2, 5 and 10 microamperes and values were read and corrected to one-thousandth of full scale.

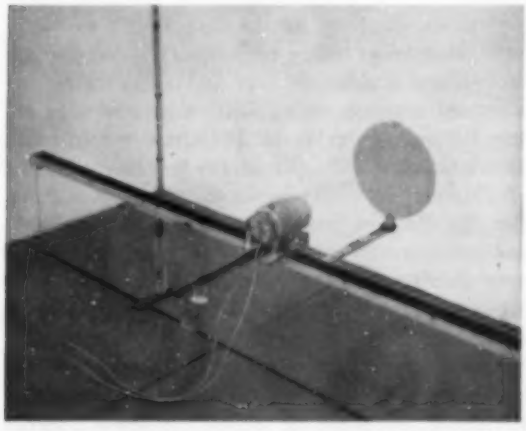

Figure 7. Horizontal track with cell, adapted to measure luminous emittance, is shown with target in position against the wall. The luminous emittance of the target is converted to illumination on the walls by dividing the target luminous emittance by the target reflection factor.

Illumination and Luminous Emittance Measurements of Wall

The measurements of wall luminous emittance were obtained by mounting the L-cell on a horizontal track which was parallel to one wall and extended the length of the wall, Figs. 2 and 6. The vertical locations of the track were set so that the distances from the cell to the ceiling were integral multiples of one-eighth of the ceiling height for each ceiling height used. The cell was moved along the track by external controls and readings were obtained for each of twelve positions equally spaced along the entire width of the wall for each vertical setting. One complete set of wall data consisted of eighty-four readings, and since the room was constructed symmetrically except for measuring devices, the values obtained for this one wall were assumed representative of all walls.

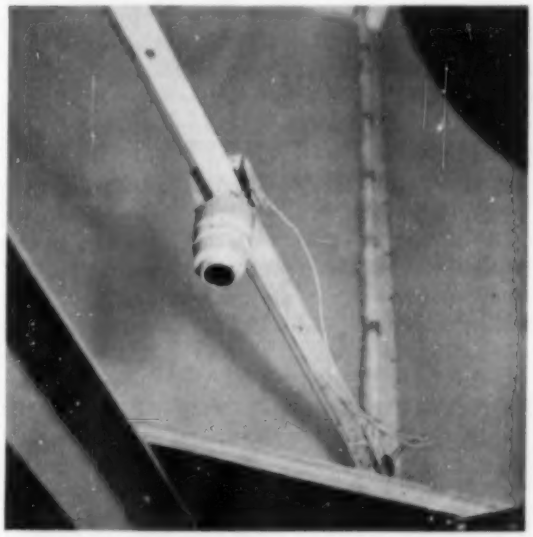

Figure 8. Sweep arm used for positioning cells to obtain data for horizontal surfaces is shown with cell, adapted for measuring the luminous emittance, mounted in an inverted position on the carrier to measure the luminous emittance of the floor.

Measurements of the illumination on the walls

were obtained by using an attachment which held a seven-inch diameter target in front of the L-cell and against the wall at each of the eighty-four positions, Fig. 7. The target reflection factor was measured, and the target luminous emittance readings were converted to illumination values by dividing the luminous emittance value by the target reflection factor. Since the target was within ¼ to ½ inch from the wall, the illumination on the wall is assumed to be the same as the illumination on the target.

Measurements of Horizontal Surfaces

A more elaborate mechanism was devised for locating the L-cell and E-cell for measuring the luminous emittance of and the illumination on the horizontal surfaces. A horizontal sweep arm, Figs. 2, 5 and 8, was welded to a vertical upright which was made to pivot about a vertical axis located in a corner of the room. The vertical distance from the ceiling to the sweep arm was continuously adjustable, and a movable carrier was placed on the arm to hold the cells. The angular positioning of the arm was controlled by the location of the pointer on the control table shown in Fig. 9. The radial setting of the carrier was made with the sweep arm in the zero degree position (parallel to one wall). The drum shown beneath the table top, Fig. 9, controlled the radial positioning of the carrier, and it was determined that ten radial sweeps were sufficient to obtain an average value for the plane being measured.

Figure 9. Control table for sweep arm. Angular position of sweep arm controlled by pointer, radial position of carrier controlled by drum under the table top, and output of the cell is recorded on the modified recorder as a function of the angular location of the arm. The cell is connected to the recorder through the voltage divider network.

Data were obtained by positioning the carrier at each of the ten radial positions and sweeping the arm through 90 degrees. The rotation of the arm was mechanically connected to a modified speedomax recorder with the drive motor disconnected so that rotation of the sweep arm from zero to ninety degrees caused eighteen one-half inch divisions of the recording paper to be passed under the recording pen.

Since the illumination and luminous emittance did not vary greatly from sweep to sweep, the output of the cells which were mounted on the carrier were connected to the recorder through a voltage divider input. This permitted a constant resistance to be maintained across the cell and different percentages of the total were applied to the recorder so that the ten curves could be separated.

The quadrant of the room cross section was divided into ten equal areas, and the radial distances for each sweep were calculated so that the path of the carrier was along the weighted centers of each of the ten equal areas. This eliminated the necessity of correcting for unequal path lengths as would have been required if equal radial spacings had been used.

The E-cell and L-cell could be mounted on the carrier in an upright position to measure the illumination on the top of horizontal planes and the luminous emittance of the ceiling, Fig. 5, or they could be mounted in an inverted position to measure the illumination on the underneath side of horizontal planes and the luminous emittance of the floor, Fig. 8. Data were obtained from the recorded curves by planimetering the area under the curves, dividing by the base length to determine the average height (deflection), correcting for the voltage divider setting, and substituting the corrected averages in calibration equations to obtain the average values of illumination and luminous emittance. All calibrations for the speedomax of illumination or luminous emittance as a function of deflection (height) were constantly checked and straight line calibration curves were obtained over wide ranges of values.

Sets of curves were obtained for the luminous emittances of the ceiling and floor as a function of the angular position of the sweep arm. Sets of curves were obtained for the illumination on top of horizontal planes located 30, 15, 7.5, 5 and 3 inches from the floor as well as for the plane located three-quarters of the ceiling height from the ceiling. Sets of curves were also obtained with the E-cell mounted inverted and located approximately 3, 5, 7.5 and

15 inches from the ceiling as well as one-quarter of the ceiling height from the ceiling.

The average values of the illumination on the tops of the horizontal planes were plotted as functions of the distance from the plane to the floor and the curves were extrapolated to obtain the illumination on the floor. The data obtained for the illumination on the underneath sides of the planes were extrapolated to obtain the illumination on the ceiling.

The ceiling reflection factor was calculated by dividing the average ceiling luminous emittance by the average illumination on the ceiling with the walls as the only source for each ceiling height. The floor reflection factor was calculated by dividing the average floor luminous emittance by the average illumination on the floor with either the ceiling or walls as the source.

Comparisons Between Experimental and Theoretical Values

Data obtained from the experimental room have been prepared in the same form as presented in the theoretical development, and the theoretical values of luminous emittance and illumination have been calculated using the basic data obtained in the experimental room. Comparisons of the results are shown in Tables 2 through 16. The room index (k_r-values) and reflection factors applicable for each test are given in the heading of each table, and these values were used in the theoretical equations to obtain the calculated values. Variations between the theoretical and experimental values are expressed in per cent of the experimental value.

$$\text{Per Cent Variation} = \frac{\text{Calculated} - \text{Experimental}}{\text{Experimental}} \times 100$$

Three ceiling heights were used which resulted in the following values for k_r.

k_r — value	Ceiling Height in Model
0.9930	71⅝ inches
0.7426	53⅝ inches
0.5200	37⅝ inches

The following conditions of test were used for each of the three values of k_r.

Source	Wall Backing
Wall	Cavity
Ceiling	Cavity
Ceiling	Opaque ($\rho_1 = 0.555$)
Floor	Cavity
Floor	Opaque ($\rho_1 = 0.555$)

Although the actual plywood floor could not be made self-luminous, floor lighting data were obtained by considering the room inverted, and reorienting the data. The original data obtained for the illumination on the underneath sides of horizontal planes near the ceiling became the illumination on the top of the horizontal planes for the inverted room with floor lighting.

The interflectance factor values presented in the tables, showing the comparisons between experimental and theoretical data, are expressed as if the surfaces were not self-luminous. This method was used because most installations will not have self-luminous surfaces, and because the ratio of E/L_0 is the same as the interflectance factor for ceiling and floor lighting and differs from the interflectance factor for wall lighting only by the factor $\frac{1}{4}\, k_r$.

The portions of the ceiling and floor lighting tables that present the wall luminous emittance data include not only the original experimental data but some also contain "corrected experimental data." This "correction" was made by multiplying the experimental value by the ratio of the average wall reflection factor to the average wall reflection factor for that particular distance from the ceiling, s. This "correction" was made in an attempt to obtain data which would be representative of an enclosure in which the wall reflection factor was uniform.

The reflection factors for the ceiling and floor for floor lighting tests are not realistic for any practical lighting problem in which the quantity of illumination or quality of the design would be considered important. Since these data represent limiting cases for floor lighting, it is to be expected that more realistic conditions would show reductions in the variations between theoretical and experimental values.

Accuracy of Basic Data

The following are the calculated accuracies of the basic data.

k_r ±0.7 per cent
ρ_1 ±5 per cent
ρ_2 ±2 per cent
ρ_3 ±2 per cent

The following is a generalized summary of the influence of the errors in the four variables.

k_r — No significant influence.

ρ_1 — The percentage changes in E/L_0 and L_1/L_0 are approximately the same as the percentage change of ρ_1, wall reflection factor, and the changes of L_2/L_0 and L_3/L_0 are considerably less than the change of ρ_1.

ρ_2 — The values of L_2/L_{01} and L_2/L_{02} are directly dependent on the ceiling reflection factor, and no anticipated error of ρ_2 would cause significant changes of the other calculated values.

ρ_3 — The values of L_3/L_{01} and L_3/L_{02} are directly dependent on the floor reflection factor, and no anticipated error of ρ_3 would cause significant changes of the other calculated values.

Conclusions

Since the variations between the experimental and theoretical values cannot be completely explained by any calculated errors that might be present in k_r, ρ_1, ρ_2 or ρ_3, Table 17, the causes of these variations must therefore be found either in the basic premises or in the failure of the experimental enclosure in duplicating the characteristics assumed in the premises. Basic data obtained for the enclosure indicate that the model room very closely approximates the conditions specified in the first four premises, and no actual room would approximate the theoretical conditions as closely.

Since none of the assumptions made in the premises, except for Premise V, have been seriously violated, it is concluded that the error made in assuming the exponential approximation for the kernel is the primary cause for the variations between the theoretical and experimental results.

Considering all of the variables present in a lighting installation, the latitude present in the specifications as to minimum recommended illumination and brightness (luminous emittance) ratios, and the uncertainties present in measuring and determining the average effective reflection factor, it might be concluded that the variations between the theoretical and experimental results obtained in this research are small enough to justify the use of the theoretical equations just as they were developed without further modifications. However, analysis of the problem leads to the conclusions that the variations were caused by the exponential approximation and were not caused by any experimental error, and therefore, the possibility exists that the theoretical equations could be modified to make them more exact.

"Correction Factors"

A study of the variations for the various values for the three different types of lighting systems shows that, if the variations for each quantity (ratio) are averaged for all test conditions of each component system, a correction factor can be calculated which will reduce the variations so that practically all of the variations are less than ±5 per cent. These correction factors are summarized in Table 18.

All theoretical values have been recalculated by multiplying by the correction factors indicated, and these "corrected calculated values" together with their variations from the experimental values are given in the set of tables from Table 19 through Table 33. Use of these correction factors has transformed the already acceptable theoretical equations into ones which predict the experimental results more accurately. Using the variations calculated in the original set of tables, Table 2 through Table 16, as guides, it would be possible to use the "uncorrected" theoretical equations or published tables and feel confident in recommending the lighting design based on them. However, if more accuracy is desired, the "correction factors" may be used.

Acknowledgments

The author wishes to express his appreciation to Professor John O. Kraehenbuehl for his guidance and advice. The author also wishes to gratefully acknowledge the assistance received from the General Education Board Fellowship for the year 1951-1952 and from the Westinghouse Electric Corporation Fellowship for the academic year 1952-1953.

References

1. Moon, P., and Spencer, D. E.: "Light Distributions in Rooms," *Journal of the Franklin Institute*, Vol. 242, No. 2, pp. 111-141 (August 1946).

2. Moon, P., and Spencer, D. E.: "Lighting Design by Interflection Method," *Journal of the Franklin Institute*, Vol. 242, No. 6, pp. 465-501 (December 1946).

3. "The Interflection Method of Predetermining Brightnesses and Brightness-Ratios," Report No. 2 of the Committee on Standards of Quality and Quantity for Interior Illumination, ILLUMINATING ENGINEERING, Vol. XLI, No. 5, pp. 361-385 (May 1946).

4. "Brightness Distribution in Rooms," Report No. 4 of the Committee on Standards of Quality and Quantity for Interior Illumination. ILLUMINATING ENGINEERING, Vol. XLII, No. 2, pp. 180-216 (February 1947).

TABLE 2.—Wall Lighting Data.

$L_{01} \neq 0, \quad L_{02} = 0, \quad L_{03} = 0; \quad k_r = 0.9930, \quad \rho_1 = 0.709, \quad \rho_2 = 0.685, \quad \rho_3 = 0.306$

h*	$f_1(h) = \frac{\rho_1}{4k_r L_{01}} E(h)$			$\frac{E(h)}{L_{01}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.5797	0.2910	0.3514	+20.8%	1.630	1.968	+20.8%
0.7500	0.3037	0.3622	+19.3	1.701	2.029	+19.3
0.8949	0.3088	0.3649	+18.1	1.730	2.044	+18.1
0.9580	0.3101	0.3641	+17.4	1.737	2.040	+17.4
1.0000	0.3108	0.3630	+16.9	1.740	2.034	+16.9

s*	$\frac{L_1(s)}{E}$			Experimental Data			$\frac{L_1(s)}{L_{01}}$		
	Exp.	Calc.	Var.†	$\rho_1(s)$	$L_{01}(s)$ ft-L	$\frac{\rho_1(s)}{4k_r L_{01}(s)}$	Exp.	Calc.	Var.†
0	——	1.081	——	——	——	——	——	2.193	——
⅛	1.270	1.103	−13.1%	0.651	176	0.0921	2.161	2.236	+3.6%
¼	1.299	1.114	−14.2	0.675	172	0.0987	2.210	2.260	+2.3
⅜	1.293	1.115	−13.7	0.706	160	0.1113	2.198	2.262	+2.9
½	1.277	1.105	−13.5	0.737	151	0.1213	2.171	2.243	+3.3
⅝	1.252	1.085	−13.3	0.746	145	0.1299	2.130	2.202	+3.4
¾	1.216	1.054	−13.3	0.754	140	0.1359	2.068	2.139	+3.4
⅞	1.168	1.012	−13.4	0.767	137	0.1406	1.986	2.053	+3.4
1	——	0.9568	——	——	——	——	——	1.942	——
Avg			−13.5%	0.709	157.3	0.1135			+3.2%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.6562	0.6743	+2.8%	$\frac{L_2}{L_{01}}$	1.116	1.367	+22.6%
$\frac{L_3}{E}$	0.3146	0.3327	+5.8%	$\frac{L_3}{L_{01}}$	0.5352	0.6751	+26.1%

TABLE 3.—Wall Lighting Data.

$L_{01} \neq 0, \quad L_{02} = 0, \quad L_{03} = 0; \quad k_r = 0.7426, \quad \rho_1 = 0.692, \quad \rho_2 = 0.685, \quad \rho_3 = 0.306$

h*	$f_1(h) = \frac{\rho_1}{4k_r L_{01}} E(h)$			$\frac{E(h)}{L_{01}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.7500	0.3386	0.3933	+16.2%	1.451	1.688	+16.3%
0.8595	0.3506	0.4004	+14.2	1.503	1.718	+14.3
0.9438	0.3547	0.4055	+14.3	1.520	1.740	+14.5
1.0000	0.3556	0.4053	+14.0	1.524	1.740	+14.2

s*	$\frac{L_1(s)}{E}$			Experimental Data			$\frac{L_1(s)}{L_{01}}$		
	Exp.	Calc.	Var.†	$\rho_1(s)$	$L_{01}(s)$ ft-L	$\frac{\rho_1(s)}{4k_r L_{01}(s)}$	Exp.	Calc.	Var.†
0	——	1.151	——	——	——	——	——	1.943	——
⅛	1.359	1.167	−14.1%	0.651	170	0.1292	1.973	1.970	−0.1%
¼	1.378	1.174	−14.8	0.667	163	0.1380	1.999	1.982	−0.9
⅜	1.379	1.174	−14.9	0.693	155	0.1500	2.001	1.982	−0.9
½	1.372	1.166	−15.0	0.710	150	0.1594	1.991	1.968	−1.3
⅝	1.345	1.150	−14.5	0.719	145	0.1668	1.951	1.941	−0.5
¾	1.319	1.126	−14.6	0.732	144	0.1691	1.915	1.900	−0.8
⅞	1.267	1.093	−13.7	0.719	143	0.1696	1.838	1.845	+0.4
1	——	1.052	——	——	——	——	——	1.776	——
Avg			−14.5%	0.692	153.8	0.1517			−0.6%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.6340	0.6588	+3.9%	$\frac{L_2}{L_{01}}$	0.9200	1.112	+20.9%
$\frac{L_3}{E}$	0.3203	0.3156	−1.5%	$\frac{L_3}{L_{01}}$	0.4649	0.5328	+14.6%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.

†Var. = Variation of calculated value (obtained by substitution in the theoretical equation) from the experimental value expressed in per cent of the experimental value.

TABLE 4.—Wall Lighting Data.

$L_{01} \neq 0, \quad L_{02} = 0, \quad L_{03} = 0; \quad k_r = 0.5200, \quad \rho_1 = 0.636, \quad \rho_2 = 0.685, \quad \rho_3 = 0.306$

h°	$f_1(h) = \frac{\rho_1}{4k_r L_{01}} E(h)$			$\frac{E(h)}{L_{01}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.5987	0.3083	0.3715	+20.5%	1.007	1.215	+20.7%
0.7500	0.3303	0.3902	+18.2	1.079	1.276	+18.3
0.9197	0.3504	0.4064	+16.0	1.145	1.329	+16.1
1.0000	0.3570	0.4124	+15.5	1.166	1.349	+15.7

s°	$\frac{L_1(s)}{E}$			Experimental Data			$\frac{L_1(s)}{L_{01}}$		
	Exp.	Calc.	Var.†	$\rho_1(s)$	$L_{01}(s)$ fc-L	$\frac{\rho_1(s)}{4k_r L_{01}(s)}$	Exp.	Calc.	Var.†
0	——	1.292	——	——	——	——	——	1.649	——
½	1.547	1.303	−15.8%	0.614	173	0.1711	1.670	1.661	−0.5%
¼	1.567	1.306	−17.7	0.619	172	0.1728	1.713	1.667	−2.6
⅜	1.580	1.306	−17.3	0.638	166	0.1846	1.705	1.666	−2.3
½	1.567	1.300	−17.0	0.641	163	0.1895	1.690	1.658	−1.9
⅝	1.548	1.288	−16.8	0.646	160	0.1945	1.671	1.644	−1.6
¾	1.520	1.273	−16.3	0.650	157	0.1995	1.640	1.623	−1.0
⅞	1.466	1.250	−14.7	0.663	151	0.2110	1.582	1.595	+0.2
1	——	1.222	——	——	——	——	——	1.560	——
Avg			−16.5%	0.636	163.4	0.1873			−1.4%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.6307	0.6500	+3.1%	$\frac{L_2}{L_{01}}$	0.6805	0.8295	+21.9%
$\frac{L_3}{E}$	0.3369	0.3234	−4.0%	$\frac{L_3}{L_{01}}$	0.3635	0.4127	+13.5%

TABLE 5.—Ceiling Lighting Data.

$L_{01} = 0, \quad L_{02} \neq 0, \quad L_{03} = 0; \quad k_r = 0.9930, \quad \rho_1 = 0.700, \quad \rho_2 = 0.685, \quad \rho_3 = 0.269$

h°	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.5767	0.4184	0.4603	+10.0%	0.6108	0.6720	+10.0%
0.7500	0.3663	0.3828	+4.5	0.5347	0.5588	+4.5
0.8949	0.3262	0.3271	−0.3	0.4791	0.4775	−0.3
0.9580	0.3127	0.3054	−2.3	0.4565	0.4458	−2.3
1.0000	0.3046	0.2917	−4.2	0.4447	0.4258	−4.3

s°	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp. Corr.	Calc.	Var.†
0	——	1.0305	——	——	——	——	——	0.5759	——
½	0.6538	0.9003	+37.7%	0.651	0.7129	+26.4%	0.3807	0.5031	+32.2%
¼	0.5923	0.7663	+33.7	0.675	0.6221	+26.4	0.3327	0.4394	+32.1
⅜	0.5510	0.6862	+24.5	0.706	0.5533	+24.0	0.2959	0.3835	+29.6
½	0.5058	0.5986	+18.3	0.727	0.4933	+21.3	0.2638	0.3345	+26.8
⅝	0.4635	0.5218	+12.6	0.746	0.4405	+18.5	0.2356	0.2916	+23.8
¾	0.4313	0.4543	+7.9	0.754	0.3961	+14.7	0.2118	0.2539	+19.9
⅞	0.3750	0.3950	+5.8	0.767	0.3466	+14.0	0.1853	0.2207	+19.1
1	——	0.3427	——	——	——	——	——	0.1915	——
Avg			+19.9%	0.709		+20.8%			+26.3%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	2.185	2.344	+7.7%	$\frac{L_2}{L_{02}}$	1.169	1.254	+7.3%
$\frac{L_3}{E}$	0.2182	0.2050	−6.0%	$\frac{L_3}{L_{02}}$	0.1167	0.1146	−1.8%

TABLE 6.—Ceiling Lighting Data.

$L_{01} = 0,\ L_{02} \neq 0,\ L_{03} = 0;\ k_r = 0.9930,\ \rho_1 = 0.555,\ \rho_2 = 0.685,\ \rho_3 = 0.269$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.5797	0.3667	0.3710	+1.3%	0.5345	0.5416	+1.3%
0.7500	0.3060	0.2969	−3.0	0.4467	0.4334	−3.0
0.8949	0.2660	0.2460	−7.5	0.3883	0.3591	−7.5
0.9580	0.2500	0.2266	−9.4	0.3650	0.3308	−9.4
1.0000	0.2390	0.2147	−10.2	0.3489	0.3134	−10.2

s*	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp.	Calc.	Var.†
0	——	0.8971	——	——	——	——	——	0.5888	——
⅛	0.5636	0.7617	+35.1%	0.554	0.5646	+34.9%	0.3518	0.3301	+31.1%
¼	0.4576	0.6473	+41.5	——	——	——	0.2044	0.2806	+37.3
⅜	0.3984	0.5506	+38.2	——	——	——	0.1780	0.2386	+34.0
½	0.3482	0.4691	+34.7	0.553	0.3495	+34.2	0.1555	0.2033	+30.7
⅝	0.3092	0.4005	+29.5	——	——	——	0.1381	0.1736	+25.7
¾	0.2746	0.3429	+24.9	——	——	——	0.1227	0.1486	+21.1
⅞	0.2366	0.2947	+24.6	0.568	0.2312	+27.5	0.1057	0.1277	+20.8
1	——	0.2547	——	——	——	——	——	0.1104	——
Avg			+32.6%	0.555		+33.3%			+28.7%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_3}{E}$	2.497	2.684	+7.5%	$\frac{L_3}{L_{02}}$	1.115	1.163	+4.3%
$\frac{L_2}{E}$	0.2087	0.1945	−6.8%	$\frac{L_2}{L_{02}}$	0.09322	0.08430	−9.6%

TABLE 7.—Ceiling Lighting Data.

$L_{01} = 0,\ L_{02} \neq 0,\ L_{03} = 0;\ k_r = 0.7426,\ \rho_1 = 0.602,\ \rho_2 = 0.685,\ \rho_3 = 0.306$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.7500	0.4225	0.4620	+9.3%	0.6168	0.6745	+9.3%
0.8595	0.3912	0.4225	+8.0	0.5711	0.6168	+8.0
0.9438	0.3708	0.3944	+6.4	0.5413	0.5758	+6.4
1.0000	0.3615	0.3768	+4.2	0.5277	0.5501	+4.3

s*	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp. Corr.	Calc.	Var.†
0	——	0.8258	——	——	——	——	——	0.5570	——
⅛	0.5704	0.7457	+30.7%	0.651	0.6063	+23.0%	0.3740	0.5039	+34.5%
¼	0.5162	0.6734	+30.5	0.667	0.5365	+25.8	0.3303	0.4542	+37.5
⅜	0.4871	0.6084	+24.9	0.693	0.4864	+25.1	0.3000	0.4103	+36.8
½	0.4546	0.5498	+20.9	0.710	0.4431	+24.1	0.2733	0.3708	+35.7
⅝	0.4213	0.4970	+18.0	0.719	0.4055	+22.6	0.2501	0.3352	+34.0
¾	0.3873	0.4496	+16.1	0.722	0.3711	+21.2	0.2289	0.3032	+32.5
⅞	0.3505	0.4069	+16.1	0.719	0.3373	+20.6	0.2080	0.2744	+31.9
1	——	0.3685	——	——	——	——	——	0.2485	——
Avg			+23.5%	0.693		+23.2%			+34.7%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_3}{E}$	1.897	1.850	−3.5%	$\frac{L_3}{L_{02}}$	1.170	1.248	+6.7%
$\frac{L_2}{E}$	0.2581	0.2495	−3.3%	$\frac{L_2}{L_{02}}$	0.1593	0.1683	+5.7%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.

†Var. = Variation of calculated value (obtained by substitution in the theoretical equation) from the experimental value expressed in per cent of the experimental value.

TABLE 8.—Ceiling Lighting Data.

$L_{01} = 0,\quad L_{02} \neq 0,\quad L_{03} = 0;\quad k_r = 0.7426,\quad \rho_1 = 0.555,\quad \rho_2 = 0.685,\quad \rho_3 = 0.269$

h°	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Calc.	Var.%	Exp.	Calc.	Var.%
0.7500	0.3772	0.3830	+1.5%	0.5507	0.5591	+1.5%
0.8595	0.3473	0.3444	−0.8	0.5070	0.5028	−0.8
0.9436	0.3263	0.3174	−2.7	0.4764	0.4634	−2.7
1.0000	0.3160	0.3007	−4.8	0.4613	0.4390	−4.8

s°	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Calc.	Var.%		Exp. Corr.	Var.%	Exp.	Calc.	Var.%
0	——	0.7007	——	——	——	——	——	0.2918	——
¼	0.4950	0.6208	+25.4%	0.556	0.4941	+25.6%	0.2726	0.3471	+27.3%
½	0.4111	0.5505	+33.9	——	——	——	0.2264	0.3078	+36.0
¾	0.3628	0.4886	+34.7	——	——	——	0.1998	0.2732	+36.7
1	0.3300	0.4343	+31.6	0.542	0.3373	+28.7	0.1817	0.2428	+33.6
⅛	0.3026	0.3865	+27.7	——	——	——	0.1666	0.2161	+29.7
¼	0.2771	0.3447	+24.4	——	——	——	0.1526	0.1927	+26.3
⅜	0.2571	0.3082	+19.9	0.568	0.2512	+22.7	0.1416	0.1723	+21.7
1	——	0.2764	——	——	——	——	——	0.1545	——
Avg			+29.2%	0.555		+25.7%			+30.2%

	Exp.	Calc.	Var.%		Exp.	Calc.	Var.%
$\frac{L_2}{E}$	2.037	2.088	+2.5%	$\frac{L_2}{L_{02}}$	1.122	1.167	+4.0%
$\frac{L_3}{E}$	0.2265	0.2113	−6.8%	$\frac{L_3}{L_{02}}$	0.1247	0.1181	−5.3%

TABLE 9.—Ceiling Lighting Data.

$L_{01} = 0,\quad L_{02} \neq 0,\quad L_{03} = 0;\quad k_r = 0.5200,\quad \rho_1 = 0.636,\quad \rho_2 = 0.685,\quad \rho_3 = 0.269$

h°	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Calc.	Var.%	Exp.	Calc.	Var.%
0.5987	0.5293	0.5704	+7.8%	0.7726	0.8327	+7.8%
0.7500	0.4906	0.5193	+5.9	0.7162	0.7580	+5.8
0.9197	0.4486	0.4672	+4.1	0.6549	0.6820	+4.1
1.0000	0.4286	0.4445	+3.7	0.6257	0.6489	+3.7

s°	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Calc.	Var.%		Exp. Corr.	Var.%	Exp. Corr.	Calc.	Var.%
0	——	0.6366	——	——	——	——	——	0.4825	——
¼	0.4946	0.5893	+19.1%	0.614	0.5133	+15.0%	0.3669	0.4466	+21.7%
½	0.4411	0.5455	+23.7	0.619	0.4532	+20.4	0.3246	0.4135	+27.4
¾	0.4208	0.5051	+20.0	0.638	0.4195	+20.4	0.3004	0.3828	+27.4
1	0.3912	0.4678	+19.6	0.641	0.3881	+20.5	0.2780	0.3546	+27.6
⅛	0.3705	0.4334	+17.0	0.646	0.3648	+18.9	0.2613	0.3285	+25.7
¼	0.3476	0.4017	+15.6	0.650	0.3401	+18.1	0.2436	0.3045	+25.0
⅜	0.3212	0.3724	+15.9	0.662	0.3081	+20.9	0.2207	0.2823	+27.9
1	——	0.3455	——	——	——	——	——	0.2619	——
Avg			+18.7%	0.636		+19.2%			+26.1%

	Exp.	Calc.	Var.%		Exp.	Calc.	Var.%
$\frac{L_2}{E}$	1.624	1.597	−1.7%	$\frac{L_2}{L_{02}}$	1.163	1.210	+4.0%
$\frac{L_3}{E}$	0.2363	0.2303	−2.5%	$\frac{L_3}{L_{02}}$	0.1693	0.1748	+3.2%

TABLE 10.—Ceiling Lighting Data.

$L_{01} = 0,\quad L_{02} \neq 0,\quad L_{03} = 0;\quad k_r = 0.5200,\quad \rho_1 = 0.555,\quad \rho_2 = 0.685,\quad \rho_3 = 0.269$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.5987	0.5118	0.5337	+4.3%	0.7472	0.7791	+4.3%
0.7500	0.4663	0.4815	+3.3	0.6807	0.7029	+3.3
0.9197	0.4247	0.4291	+1.0	0.6200	0.6264	+1.0
1.0000	0.4092	0.4065	−0.7	0.5974	0.5934	−0.7

s*	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp.	Calc.	Var.†
0	——	0.5646	——	——	——	——	——	0.3969	——
⅛	0.4607	0.5195	+12.8%	——	——	——	0.3136	0.3652	+16.5%
¼	0.3941	0.4762	+21.3	0.554	0.3948	+21.1%	0.2682	0.3361	+25.3
⅜	0.3533	0.4406	+24.7	——	——	——	0.2405	0.3097	+28.8
½	0.3253	0.4063	+24.9	0.544	0.3319	+22.4	0.2214	0.2856	+29.0
⅝	0.3033	0.3750	+23.6	——	——	——	0.2065	0.2636	+27.7
¾	0.2837	0.3466	+22.2	0.553	0.2847	+21.7	0.1931	0.2436	+26.2
⅞	0.2655	0.3208	+20.8	——	——	——	0.1807	0.2255	+24.8
1	——	0.2973	——	——	——	——	——	0.2090	——
Avg			+21.5%	0.555		+21.7%			+25.5%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	1.671	1.671	0.0%	$\frac{L_2}{L_{02}}$	1.137	1.175	+3.3%
$\frac{L_3}{E}$	0.2405	0.2271	−5.6%	$\frac{L_3}{L_{02}}$	0.1637	0.1596	−2.5%

TABLE 11.—Floor Lighting Data.

$L_{01} = 0,\quad L_{02} = 0,\quad L_{03} \neq 0;\quad k_r = 0.9930,\quad \rho_1 = 0.709,\quad \rho_2 = 0.269,\quad \rho_3 = 0.685$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.7500	0.1426	0.1925	+35%	0.2062	0.2810	+35%
0.8949	0.1574	0.2274	+44	0.2296	0.3320	+44
0.9527	0.1638	0.2411	+47	0.2391	0.3520	+47
1.0000	0.1687	0.2540	+51	0.2463	0.3708	+51

s*	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp. Corr.	Calc.	Var.†
0	——	0.6817	——	——	——	——	——	0.1916	——
⅛	0.9630	0.7599	−21.1%	0.767	0.8902	−14.4%	0.1854	0.3136	+15.2%
¼	1.081	0.8510	−21.3	0.754	1.0170	−16.2	0.2118	0.2394	+13.0
⅜	1.190	0.9591	−19.4	0.746	1.1311	−15.2	0.2334	0.2695	+15.5
½	1.299	1.084	−16.6	0.727	1.267	−14.4	0.2637	0.3045	+15.5
⅝	1.415	1.230	−13.1	0.706	1.421	−13.4	0.2959	0.3456	+16.8
¾	1.521	1.393	−8.4	0.675	1.598	−12.8	0.3327	0.3916	+17.7
⅞	1.679	1.584	−5.7	0.651	1.829	−13.4	0.3808	0.4452	+16.9
1	——	1.804	——	——	——	——	——	0.5069	——
Avg			−15.1%	0.709		−14.3%			+15.8%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.5602	0.4076	−27.2%	$\frac{L_2}{L_{02}}$	0.1167	0.1145	−1.9%
$\frac{L_3}{E}$	5.612	4.498	−19.8%	$\frac{L_3}{L_{02}}$	1.169	1.254	+7.3%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.

†Var. = Variation of calculated value (obtained by substitution in the theoretical equation) from the experimental value expressed in per cent of the experimental value.

TABLE 12.—Floor Lighting Data.

$L_{01} = 0,\ L_{02} = 0,\ L_{03} \neq 0;\ k_r = 0.9930,\ \rho_1 = 0.555,\ \rho_2 = 0.269,\ \rho_3 = 0.685$

h*	$f_0(h) = \rho_0 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.7506	0.09015	0.1199	+33%	0.1316	0.1750	+33%
0.8949	0.1024	0.1430	+40	0.1496	0.2088	+40
0.9527	0.1089	0.1537	+41	0.1590	0.2243	+41
1.0000	0.1151	0.1631	+42	0.1680	0.2380	+42

s*	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp.	Calc.	Var.†
0	——	0.6307	——	——	——	——	——	0.1104	——
⅛	0.8030	0.7231	−10.1%	0.568	0.7846	−8.0%	0.1058	0.1264	+19.5%
¼	0.9318	0.8332	−10.6	——	——	——	0.1227	0.1458	+18.8
⅜	1.049	0.9672	−7.8	——	——	——	0.1383	0.1693	+22.4
½	1.182	1.128	−4.6	0.553	1.196	−4.9	0.1556	0.1974	+26.9
⅝	1.352	1.320	−2.4	——	——	——	0.1780	0.2309	+29.7
¾	1.553	1.548	−0.3	——	——	——	0.2042	0.2708	+32.6
⅞	1.913	1.818	−5.0	0.554	1.916	−5.1	0.2516	0.3182	+26.5
1	——	2.139	——	——	——	——	——	0.3742	——
Avg			−5.8%	0.555		−6.0%			+25.2%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.7083	0.4816	−32.0%	$\frac{L_2}{L_{03}}$	0.09323	0.06430	−0.6%
$\frac{L_3}{E}$	0.472	0.647	−31.6%	$\frac{L_3}{L_{03}}$	1.115	1.163	+4.3%

TABLE 13.—Floor Lighting Data.

$L_{01} = 0,\ L_{02} = 0,\ L_{03} \neq 0;\ k_r = 0.7426,\ \rho_1 = 0.692,\ \rho_2 = 0.306,\ \rho_3 = 0.685$

h*	$f_0(h) = \rho_0 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.7500	0.1449	0.2032	+40%	0.2116	0.2967	+40%
0.8595	0.1523	0.2216	+46	0.2224	0.3235	+45
0.9368	0.1597	0.2357	+48	0.2332	0.3441	+48
1.0000	0.1609	0.2479	+46	0.2481	0.3619	+46

s*	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp. Corr.	Calc.	Var.†
0	——	0.8377	——	——	——	——	——	0.2485	——
⅛	1.022	0.9084	−11.1%	0.719	0.9834	−7.6%	0.2081	0.2695	+29.5%
¼	1.139	0.9987	−12.4	0.733	1.062	−8.6	0.2290	0.2933	+28.1
⅜	1.238	1.080	−12.1	0.719	1.182	−8.6	0.2501	0.3203	+28.1
½	1.325	1.182	−10.8	0.710	1.292	−8.5	0.2734	0.3506	+28.2
⅝	1.420	1.297	−8.7	0.693	1.416	−8.5	0.3001	0.3847	+28.2
¾	1.505	1.435	−5.3	0.667	1.561	−8.7	0.3303	0.4228	+28.0
⅞	1.663	1.569	−5.7	0.651	1.707	−11.3	0.3739	0.4655	+24.5
1	——	1.739	——	——	——	——	——	0.5131	——
Avg			−9.4%	0.692		−8.8%			+27.8%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.7524	0.5673	−24.6%	$\frac{L_2}{L_{03}}$	0.1593	0.1688	+5.7%
$\frac{L_3}{E}$	5.529	4.206	−23.9%	$\frac{L_3}{L_{03}}$	1.170	1.248	+6.7%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.

†Var. = Variation of calculated value (obtained by substitution in the theoretical equation) from the experimental value expressed in per cent of the experimental value.

TABLE 14.—Floor Lighting Data.

$L_{01} = 0$, $L_{02} = 0$, $L_{03} \neq 0$; $k_r = 0.7426$, $\rho_1 = 0.555$, $\rho_2 = 0.269$, $\rho_3 = 0.685$

h°	$f_3(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.7196	0.1049	0.1313	+25%	0.1531	0.1917	+25%
0.7500	0.1056	0.1347	+28	0.1541	0.1967	+28
0.8595	0.1121	0.1479	+32	0.1637	0.2160	+32
0.9368	0.1173	0.1583	+35	0.1712	0.2311	+35
1.0000	0.1221	0.1674	+37	0.1782	0.2444	+37

s°	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp.	Calc.	Var.†
0	——	0.7859	——	——	——	——	——	0.1546	——
⅛	0.9186	0.8688	−5.4%	0.568	0.8976	−3.2%	0.1415	0.1709	+20.8%
¼	0.9902	0.9651	−2.5	——	——	——	0.1525	0.1898	+24.5
⅜	1.081	1.076	−0.5	——	——	——	0.1668	0.2117	+26.9
½	1.179	1.204	+2.1	0.543	1.205	+0.1	0.1817	0.2368	+30.3
⅝	1.296	1.350	+4.2	——	——	——	0.1999	0.2655	+32.8
¾	1.469	1.517	+3.3	——	——	——	0.2263	0.2983	+31.8
⅞	1.769	1.707	−3.5	0.556	1.766	−0.3	0.2725	0.3357	+23.2
1	——	1.923	——	——	——	——	——	0.3782	——
Avg			−0.3%	0.555		−2.2%			+27.2%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.8094	0.6003	−25.8%	$\frac{L_2}{L_{03}}$	0.1247	0.1181	−5.3%
$\frac{L_3}{E}$	7.280	5.935	−18.5%	$\frac{L_3}{L_{03}}$	1.123	1.167	+4.0%

TABLE 15.—Floor Lighting Data.

$L_{01} = 0$, $L_{02} = 0$, $L_{03} \neq 0$; $k_r = 0.5200$, $\rho_1 = 0.636$, $\rho_2 = 0.269$, $\rho_3 = 0.685$

h°	$f_3(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.7500	0.1495	0.1814	+21.3%	0.2183	0.2649	+21.3%
0.7993	0.1516	0.1867	+23.2	0.2214	0.2726	+23.2
0.9097	0.1573	0.1993	+26.8	0.2296	0.2909	+26.8
1.0000	0.1628	0.2102	+29.1	0.2377	0.3069	+29.1

s°	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp. Corr.	Calc.	Var.†
0	——	0.9886	——	——	——	——	——	0.2618	——
⅛	1.054	1.053	−0.1%	0.662	1.011	+4.2%	0.2207	0.2788	+26.3%
¼	1.141	1.123	−1.6	0.650	1.116	+0.6	0.3436	0.2976	+22.2
⅜	1.215	1.201	−1.2	0.646	1.197	+0.4	0.3613	0.3181	+21.7
½	1.383	1.386	+0.2	0.641	1.373	+1.0	0.2779	0.3406	+22.6
⅝	1.381	1.379	−0.1	0.638	1.376	+0.3	0.3004	0.3652	+21.6
¾	1.447	1.480	+2.3	0.619	1.487	−0.5	0.3246	0.3921	+20.8
⅞	1.623	1.591	−2.0	0.614	1.681	−5.4	0.3670	0.4213	+14.8
1	——	1.711	——	——	——	——	——	0.4532	——
Avg			−0.4%	0.636		−0.1%			+21.4%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.7753	0.6599	−15.0%	$\frac{L_2}{L_{03}}$	0.1692	0.1745	+3.1%
$\frac{L_3}{E}$	5.328	4.569	−14.2%	$\frac{L_3}{L_{03}}$	1.163	1.210	+4.0%

TABLE 16.—Floor Lighting Data.

$L_{01} = 0, \quad L_{02} = 0, \quad L_{03} \neq 0; \quad k_r = 0.5200, \quad \rho_1 = 0.555, \quad \rho_2 = 0.269, \quad \rho_3 = 0.685$

h^*	$f_0(h) = \rho_0 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Calc.	Var.†	Exp.	Calc.	Var.†
0.5997	0.1213	0.1406	+15.9%	0.1771	0.2053	+15.9%
0.7500	0.1266	0.1521	+20.1	0.1849	0.2220	+20.1
0.7993	0.1298	0.1562	+20.3	0.1895	0.2280	+20.3
0.9097	0.1351	0.1660	+22.9	0.1972	0.2424	+22.9
1.0000	0.1377	0.1748	+26.9	0.2011	0.2552	+26.9

p^*	$\frac{L_1(s)}{E}$			$\rho_1(s)$	$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Calc.	Var.†		Exp. Corr.	Var.†	Exp.	Calc.	Var.†
0	——	0.9414	——	——	——	——	——	0.2090	——
⅛	0.9771	0.9985	+2.2%	——	——	——	0.1806	0.2217	+22.8%
¼	1.045	1.063	+1.7	0.553	1.048	+1.4%	0.1929	0.2360	+22.3
⅜	1.117	1.136	+1.7	——	——	——	0.2066	0.2521	+22.0
½	1.194	1.217	+1.8	0.544	1.222	−0.4	0.2216	0.2702	+21.9
⅝	1.301	1.307	+0.5	——	——	——	0.2406	0.2906	+20.6
¾	1.451	1.408	−3.0	0.554	1.454	−3.2	0.2682	0.3125	+16.5
⅞	1.696	1.518	−10.5	——	——	——	0.3136	0.3370	+7.5
1	——	1.641	——	——	——	——	——	0.3643	——
Avg			−0.8%	0.555		−0.7%			+19.1%

	Exp.	Calc.	Var.†		Exp.	Calc.	Var.†
$\frac{L_2}{E}$	0.8858	0.7191	−18.8%	$\frac{L_2}{L_{03}}$	0.1636	0.1596	−2.4%
$\frac{L_3}{E}$	6.153	5.292	−14.0%	$\frac{L_3}{L_{03}}$	1.137	1.175	+3.3%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.

†Var. = Variation of calculated value (obtained by substitution in the theoretical equation) from the experimental value expressed in per cent of the experimental value.

TABLE 17.—Influence of k_r, ρ_1, ρ_2, and ρ_3 on the ceiling lighting calculated values which were obtained by substitution in the theoretical equations. Data are given in per cent variation of the recalculated and experimental values from original calculated values which are given in Table 5.

	k_r		ρ_1		ρ_2		ρ_3		Exp.
Var.	+0.7%	−0.7%	+10%	−10%	+5%	−5%	+20%	−20%	0%
k_r	1.0000	0.9861	0.9930	0.9930	0.993	0.993	0.9930	0.9930	0.9930
ρ_1	0.709	0.709	0.780	0.638	0.709	0.709	0.709	0.709	0.709
ρ_2	0.685	0.685	0.685	0.685	0.719	0.651	0.685	0.685	0.685
ρ_3	0.269	0.269	0.269	0.269	0.269	0.269	0.314	0.310	0.269
f (0.75)	−0.4%	+0.4%	+14.7%	−11.6%	+6.3%	−6.1%	+1.1%	−1.4%	−4.3%
$\frac{E\,(0.75)}{L_{00}}$	−0.5	+0.6	+14.7	−11.6	+1.3	−1.2	+1.2	−1.4	−4.3
$\frac{L_1\,(0)}{E}$	−0.6	+0.6	+4.4	−5.4	0.0	0.0	−0.4	+0.4	——
$\frac{L_1\,(\frac{1}{4})}{E}$	−0.4	+0.4	+7.4	−7.8	0.0	0.0	+0.1	−0.2	−20.9
$\frac{L_1\,(\frac{1}{2})}{E}$	−0.2	+0.2	+10.0	−10.0	0.0	0.0	+0.8	−1.1	−17.6
$\frac{L_1\,(\frac{3}{4})}{E}$	0.0	0.0	+13.0	−11.5	0.0	0.0	+2.0	−2.6	−13.8
$\frac{L_1\,(1)}{E}$	−0.2	+0.2	+13.8	−12.3	0.0	0.0	+4.2	−4.4	——
$\frac{L_1\,(0)}{L_{00}}$	0.0	0.0	+19.8	−16.4	+1.3	−1.3	+0.9	−1.1	——
$\frac{L_1\,(\frac{1}{4})}{L_{00}}$	−0.2	+0.2	+23.2	−18.6	+1.3	−1.3	+1.3	−1.6	−24.3
$\frac{L_1\,(\frac{1}{2})}{L_{00}}$	−0.3	+0.4	+26.2	−20.4	+1.3	−1.2	+2.0	−2.5	−21.1
$\frac{L_1\,(\frac{3}{4})}{L_{00}}$	−0.6	+0.6	+28.4	−21.8	+1.3	−1.3	+3.2	−4.1	−16.6
$\frac{L_1\,(1)}{L_{00}}$	−0.7	+0.8	+29.5	−22.3	+1.4	−1.2	+5.4	−6.7	——
$\frac{L_2}{E}$	−0.6	+0.6	−8.8	+8.9	0.0	0.0	−0.7	+0.9	−3.6
$\frac{L_2}{L_{00}}$	0.0	0.0	+4.6	−3.7	+1.3	−1.3	+0.5	−0.6	−6.8
$\frac{L_3}{E}$	−0.3	+0.1	+2.5	−2.0	0.0	0.0	+17.4	−22.6	+6.4
$\frac{L_3}{L_{00}}$	−0.8	+0.7	+17.5	−13.5	+1.2	−1.3	+16.8	−23.7	+1.8

TABLE 18.—"Correction Factors." Component equations are to be multiplied by the appropriate "correction factors."

Ratio	Component Lighting System		
	Wall	Ceiling	Floor
$E\,(0.75)/L_0$	0.95	0.97	0.77
$L_1\,(s)/L_0$	1.00	0.78	0.82
L_2/L_0	0.82	0.95	1.02
L_3/L_0	0.85	1.02	0.95
f	0.85	0.97	0.77
$L_1\,(s)/E\,(0.75)$	1.17	0.81	1.06
$L_2/E\,(0.75)$	0.97	0.99	1.31
$L_3/E\,(0.75)$	1.00	1.05	1.23

TABLE 19.—Wall Lighting Data with "Corrected Calculated Values."

$L_{01} \neq 0,\ L_{02} = 0,\ L_{03} = 0;\ k_r = 0.9930,\ \rho_1 = 0.709,\ \rho_2 = 0.685,\ \rho_3 = 0.306$

h'	$f_1(h) = \frac{\rho_1}{4k_r L_{01}} E(h)$			$\frac{E(h)}{L_{01}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.5797	0.2910	0.2987	+2.6%	1.630	1.673	+2.6%
0.7500	0.3037	0.3079	+1.4	1.701	1.725	+1.4
0.8949	0.3088	0.3101	+0.4	1.730	1.737	+0.4
0.9560	0.3101	0.3095	−0.2	1.737	1.734	−0.2
1.0000	0.3106	0.3086	−0.6	1.740	1.729	−0.6

s'	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{L_{01}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	1.265	——	——	2.193	——
⅛	1.270	1.291	+1.6%	2.161	2.238	+3.6%
¼	1.299	1.303	+0.3	2.210	2.260	+2.3
⅜	1.302	1.305	+1.0	2.198	2.262	+2.9
½	1.277	1.293	+1.3	2.171	2.243	+3.3
⅝	1.253	1.269	+1.4	2.130	2.202	+3.4
¾	1.216	1.233	+1.4	2.068	2.139	+3.4
⅞	1.168	1.184	+1.4	1.986	2.053	+3.4
1	——	1.119	——	——	1.942	——
Avg			+1.3%			+3.2%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.6562	0.6541	−0.3%	$\frac{L_2}{L_{01}}$	1.116	1.122	+0.5%
$\frac{L_3}{E}$	0.3146	0.3327	+5.8%	$\frac{L_3}{L_{01}}$	0.5352	0.5738	+7.2%

TABLE 20.—Wall Lighting Data with "Corrected Calculated Values."

$L_{01} \neq 0,\ L_{02} = 0,\ L_{03} = 0;\ k_r = 0.7426,\ \rho_1 = 0.692,\ \rho_2 = 0.685,\ \rho_3 = 0.306$

h'	$f_1(h) = \frac{\rho_1}{4k_r L_{01}} E(h)$			$\frac{E(h)}{L_{01}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7500	0.3386	0.3343	−1.3%	1.451	1.435	−1.1%
0.8595	0.3506	0.3403	−2.9	1.503	1.460	−2.9
0.9438	0.3547	0.3448	−2.8	1.520	1.479	−2.7
1.0000	0.3556	0.3446	−3.1	1.524	1.479	−3.0

s'	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{L_{01}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	1.347	——	——	1.943	——
⅛	1.359	1.365	+0.4%	1.973	1.970	−0.1%
¼	1.378	1.374	−0.3	1.999	1.982	−0.9
⅜	1.379	1.374	−0.4	2.001	1.983	−0.9
½	1.372	1.364	−0.6	1.991	1.969	−1.3
⅝	1.345	1.345	0.0	1.951	1.941	−0.5
¾	1.319	1.317	−0.2	1.915	1.900	−0.8
⅞	1.267	1.279	+0.9	1.838	1.845	+0.4
1	——	1.231	——	——	1.776	——
Avg			−0.03%			−0.6%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.6340	0.6390	+0.7%	$\frac{L_2}{L_{01}}$	0.9200	0.9118	−0.9%
$\frac{L_3}{E}$	0.3203	0.3156	−1.5%	$\frac{L_3}{L_{01}}$	0.4649	0.4529	−2.6%

TABLE 21.—Wall Lighting Data with "Corrected Calculated Values."

$L_{01} \neq 0,\ L_{02} = 0,\ L_{03} = 0;\ k_r = 0.5200,\ \rho_1 = 0.636,\ \rho_2 = 0.685,\ \rho_3 = 0.306$

h*	$f_1(h) = \frac{\rho_1}{4k_r L_{01}} E(h)$			$\frac{E(h)}{L_{01}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.5987	0.3083	0.3158	+2.4%	1.007	1.033	+2.6%
0.7500	0.3302	0.3317	+0.5	1.079	1.085	+0.5
0.9197	0.3504	0.3454	−1.4	1.145	1.130	−1.3
1.0000	0.3570	0.3505	−1.8	1.166	1.147	−1.6

s*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{L_{01}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	1.513	——	——	1.649	——
⅛	1.547	1.523	−1.6%	1.670	1.661	−0.5%
¼	1.567	1.528	−2.7	1.713	1.667	−2.6
⅜	1.580	1.528	−3.3	1.705	1.666	−2.3
½	1.567	1.521	−2.9	1.690	1.658	−1.9
⅝	1.548	1.507	−2.6	1.671	1.644	−1.6
¾	1.520	1.488	−2.1	1.640	1.623	−1.0
⅞	1.466	1.463	−0.3	1.582	1.595	+0.2
1	——	1.430	——	——	1.560	——
Avg			−2.3%			−1.4%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.6307	0.6305	0.0%	$\frac{L_2}{L_{01}}$	0.6805	0.6802	0.0%
$\frac{L_3}{E}$	0.3369	0.3234	−4.0%	$\frac{L_3}{L_{01}}$	0.3635	0.3508	−3.5%

TABLE 22.—Ceiling Lighting Data with "Corrected Calculated Values."

$L_{01} = 0,\ L_{02} \neq 0,\ L_{03} = 0;\ k_r = 0.9930,\ \rho_1 = 0.709,\ \rho_2 = 0.685,\ \rho_3 = 0.269$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.5797	0.4184	0.4465	+6.7%	0.6108	0.6518	+6.7%
0.7500	0.3663	0.3713	+1.4	0.5347	0.5421	+1.4
0.8949	0.3282	0.3173	−3.3	0.4791	0.4632	−3.3
0.9580	0.3127	0.2962	−5.3	0.4565	0.4324	−5.3
1.0000	0.3046	0.2829	−7.1	0.4447	0.4130	−7.1

s*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp. Corr.	Corr. Calc.	Var.†
0	——	0.6347	——	——	——	——	0.4492	——
⅛	0.6538	0.7292	+11.5%	0.7130	+2.4%	0.3807	0.3934	+3.1%
¼	0.5923	0.6368	+7.5	0.6231	+2.4	0.3327	0.3427	+3.0
⅜	0.5510	0.5558	+0.9	0.5533	+0.5	0.3059	0.2991	+1.1
½	0.5058	0.4849	−4.1	0.4933	−1.7	0.2638	0.2609	−1.1
⅝	0.4635	0.4227	−8.8	0.4405	−4.0	0.2356	0.2274	−3.5
¾	0.4212	0.3680	−12.6	0.3961	−7.1	0.2116	0.1980	−6.5
⅞	0.3750	0.3200	−14.7	0.3466	−7.7	0.1853	0.1721	−7.1
1	——	0.2776	——	——	——	——	0.1494	——
Avg			−9.9%		−3.3%			−1.6%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	2.185	2.223	+1.7%	$\frac{L_2}{L_{02}}$	1.169	1.191	+1.9%
$\frac{L_3}{E}$	0.2162	0.2153	−1.3%	$\frac{L_3}{L_{02}}$	0.1167	0.1169	+0.2%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.

†Var. = Variation of calculated value (obtained by substitution in the theoretical equation with its correction factor) from the experimental value expressed in per cent of the experimental value.

TABLE 23.—Ceiling Lighting Data with "Corrected Calculated Values."

$L_{01} = 0$, $L_{02} \neq 0$, $L_{03} = 0$; $k_r = 0.9930$, $\rho_1 = 0.555$, $\rho_2 = 0.685$, $\rho_3 = 0.269$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.5797	0.3667	0.3600	−1.7%	0.5345	0.5254	−1.7%
0.7500	0.3060	0.2880	−5.9	0.4467	0.4204	−5.9
0.8949	0.2660	0.2386	−10.3	0.3883	0.3483	−10.3
0.9580	0.2500	0.2198	−12.1	0.3650	0.3209	−12.1
1.0000	0.2390	0.2083	−12.8	0.3489	0.3040	−12.8

s*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	0.7267	——	——	——	——	0.3033	——
⅛	0.5626	0.6170	+9.5%	0.5646	+9.3%	0.2518	0.2575	+2.3%
¼	0.4576	0.5243	+14.6	——	——	0.2044	0.2189	+7.1
⅜	0.3984	0.4460	+11.9	——	——	0.1780	0.1861	+4.6
½	0.3492	0.3800	+9.1	0.3495	+8.7	0.1555	0.1586	+2.0
⅝	0.3092	0.3244	+4.9	——	——	0.1381	0.1354	−2.0
¾	0.2746	0.2777	+1.1	——	——	0.1227	0.1159	−5.5
⅞	0.2366	0.2387	+0.9	0.2313	+3.2	0.1057	0.09961	−5.8
1	——	0.2063	——			——	0.08611	——
Avg			+7.4%		+7.1%			+0.4%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	2.497	2.657	+6.4%	$\frac{L_2}{L_{02}}$	1.115	1.105	−0.9%
$\frac{L_3}{E}$	0.3087	0.2949	−2.2%	$\frac{L_3}{L_{02}}$	0.09323	0.08599	−7.8%

TABLE 24.—Ceiling Lighting Data with "Corrected Calculated Values."

$L_{01} = 0$, $L_{02} \neq 0$, $L_{03} = 0$; $k_r = 0.7426$, $\rho_1 = 0.602$, $\rho_2 = 0.685$, $\rho_3 = 0.306$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7500	0.4225	0.4481	+6.1%	0.6168	0.6543	+6.1%
0.8595	0.3912	0.4098	+4.8	0.5711	0.5983	+4.8
0.9438	0.3708	0.3826	+3.2	0.5413	0.5585	+3.2
1.0000	0.3615	0.3655	+1.1	0.5277	0.5336	+1.1

s*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp. Corr.	Corr. Calc.	Var.†
0	——	0.6689	——	——	——	——	0.4345	——
⅛	0.5704	0.6040	+5.9%	0.6063	−0.4%	0.3740	0.3923	+4.9%
¼	0.5163	0.5455	+5.7	0.5355	+1.9	0.3303	0.3543	+7.3
⅜	0.4871	0.4928	+1.2	0.4864	+1.3	0.3000	0.3200	+6.7
½	0.4546	0.4453	−2.0	0.4431	+0.5	0.2733	0.2892	+5.8
⅝	0.4213	0.4026	−4.4	0.4055	−0.7	0.2501	0.2615	+4.6
¾	0.3872	0.3643	−5.9	0.3711	−1.9	0.2289	0.2365	+3.3
⅞	0.3505	0.3296	−6.0	0.3373	−3.3	0.2080	0.2140	+2.9
1	——	0.2985	——	——	——	——	0.1938	——
Avg			−0.8%		−0.2%			+5.1%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	1.897	1.832	−3.4%	$\frac{L_2}{L_{02}}$	1.170	1.186	+1.4%
$\frac{L_3}{E}$	0.2581	0.2620	+1.5%	$\frac{L_3}{L_{02}}$	0.1592	0.1717	+7.9%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.
†Var. = Variation of calculated value (obtained by substitution in the theoretical equation with its correction factor) from the experimental value expressed in per cent of the experimental value.

TABLE 25.—Ceiling Lighting Data with "Corrected Calculated Values."

$L_{01} = 0, \quad L_{02} \neq 0, \quad L_{03} = 0; \quad k_r = 0.7426, \quad \rho_1 = 0.555, \quad \rho_2 = 0.685, \quad \rho_3 = 0.269$

h°	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7500	0.3772	0.3715	−1.5%	0.5507	0.5423	−1.5%
0.8595	0.3473	0.3341	−3.8	0.5070	0.4877	−3.8
0.9438	0.3263	0.3079	−5.6	0.4764	0.4495	−5.6
1.0000	0.3160	0.2917	−7.7	0.4613	0.4258	−7.7

s°	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	0.5676	——	——	——	——	0.3056	——
⅛	0.4950	0.5028	+1.6%	0.4941	+1.8%	0.2726	0.2707	−0.7%
¼	0.4111	0.4459	+8.5	——	——	0.2264	0.2401	+6.1
⅜	0.3628	0.3958	+9.1	——	——	0.1998	0.2131	+6.7
½	0.3300	0.3517	+6.6	0.3373	+4.3	0.1817	0.1894	+4.2
⅝	0.3026	0.3131	+3.5	——	——	0.1666	0.1686	+1.2
¾	0.2771	0.2793	+0.8	——	——	0.1526	0.1503	−1.5
⅞	0.2571	0.2496	−2.9	0.2512	−0.6	0.1416	0.1344	−5.1
1	——	0.2239	——	——	——	——	0.1205	——
Avg			+3.9%		+1.8%			+1.6%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	2.037	2.067	+1.5%	$\frac{L_2}{L_{02}}$	1.123	1.109	−1.2%
$\frac{L_3}{E}$	0.2265	0.2218	−2.1%	$\frac{L_3}{L_{02}}$	0.1247	0.1205	−3.4%

TABLE 26.—Ceiling Lighting Data with "Corrected Calculated Values."

$L_{01} = 0, \quad L_{02} \neq 0, \quad L_{03} = 0; \quad k_r = 0.5200, \quad \rho_1 = 0.636, \quad \rho_2 = 0.685, \quad \rho_3 = 0.269$

h°	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.5987	0.5292	0.5533	+4.6%	0.7736	0.8077	+4.5%
0.7500	0.4906	0.5036	+2.6	0.7162	0.7352	+2.6
0.9197	0.4486	0.4532	+1.0	0.6549	0.6615	+1.0
1.0000	0.4286	0.4312	+0.6	0.6257	0.6294	+0.6

s°	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp. Corr.	Corr. Calc.	Var.†
0	——	0.5156	——	——	——	——	0.3764	——
⅛	0.4946	0.4773	−3.5%	0.5123	−6.8%	0.3669	0.3483	−5.1%
¼	0.4411	0.4419	+0.2	0.4532	−2.5	0.3246	0.3225	−0.6
⅜	0.4208	0.4091	−2.8	0.4195	−2.5	0.3004	0.2986	−0.6
½	0.3912	0.3789	−3.1	0.3881	−2.4	0.2780	0.2766	−0.5
⅝	0.3705	0.3511	−5.3	0.3648	−3.8	0.2613	0.2562	−2.0
¾	0.3476	0.3254	−6.4	0.3401	−4.3	0.2436	0.2375	−2.5
⅞	0.3213	0.3016	−6.1	0.3081	−2.1	0.2207	0.2203	−0.2
1	——	0.2799	——	——	——	——	0.2043	——
Avg			−3.8%		−3.5%			−1.6%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	1.634	1.581	−3.6%	$\frac{L_2}{L_{02}}$	1.163	1.150	−1.1%
$\frac{L_3}{E}$	0.2363	0.2418	+2.3%	$\frac{L_3}{L_{02}}$	0.1602	0.1781	+5.3%

TABLE 27.—Ceiling Lighting Data with "Corrected Calculated Values."

$L_{01} = 0,\ L_{02} \neq 0,\ L_{03} = 0;\ k_r = 0.5200,\ \rho_1 = 0.555,\ \rho_2 = 0.685,\ \rho_3 = 0.269$

h*	$f_2(h) = \rho_2 \frac{E(h)}{L_{02}}$			$\frac{E(h)}{L_{02}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.5987	0.5118	0.5177	+1.2%	0.7472	0.7557	+1.1%
0.7500	0.4663	0.4671	+0.2	0.6807	0.6818	+0.2
0.9197	0.4247	0.4162	−2.0	0.6200	0.6076	−2.0
1.0000	0.4093	0.3943	−3.6	0.5974	0.5756	−3.6

s*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{01}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	0.4573	——	——	——	——	0.3096	——
⅛	0.4607	0.4208	−8.7%	——	——	0.3136	0.2849	−9.2%
¼	0.3941	0.3873	−1.7	0.3948	−1.9%	0.2683	0.2623	−2.3
⅜	0.3533	0.3569	+1.0	——	——	0.2405	0.2416	+0.5
½	0.3253	0.3291	+1.3	0.3319	−0.8	0.2214	0.2228	+0.6
⅝	0.3038	0.3037	+0.1	——	——	0.2065	0.2056	−0.4
¾	0.2837	0.2807	−1.1	0.2847	−1.4	0.1931	0.1900	−1.6
⅞	0.2655	0.2598	−2.1	——	——	0.1807	0.1759	−2.7
1	——	0.2408	——	——	——	——	0.1630	——
Avg			−1.8%		−1.4%			−3.3%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_1}{E}$	1.671	1.654	−1.0%	$\frac{L_1}{L_{01}}$	1.137	1.116	−1.8%
$\frac{L_2}{E}$	0.2405	0.2368	−0.8%	$\frac{L_2}{L_{02}}$	0.1637	0.1628	−0.5%

TABLE 28.—Floor Lighting Data with "Corrected Calculated Values."

$L_{01} = 0,\ L_{02} = 0,\ L_{03} \neq 0;\ k_r = 0.9030,\ \rho_1 = 0.709,\ \rho_2 = 0.269,\ \rho_3 = 0.685$

h*	$f_3(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7500	0.1426	0.1482	+3.9%	0.2082	0.2164	+3.9%
0.8949	0.1574	0.1751	+11.2	0.2296	0.2556	+11.3
0.9537	0.1636	0.1856	+13.3	0.2391	0.2710	+13.3
1.0000	0.1687	0.1956	+15.9	0.2463	0.2855	+15.9

s*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp. Corr.	Corr. Calc.	Var.†
0	——	0.7226	——	——	——	——	0.1571	——
⅛	0.9630	0.8055	−16.4%	0.8902	−9.5%	0.1854	0.1753	−5.5%
¼	1.081	0.9030	−16.5	1.017	−11.3	0.2118	0.1963	−7.3
⅜	1.190	1.017	−14.5	1.131	−10.1	0.2334	0.2210	−5.3
½	1.299	1.149	−11.5	1.267	−9.3	0.2637	0.2497	−5.3
⅝	1.415	1.304	−7.8	1.421	−8.3	0.2959	0.2834	−4.2
¾	1.521	1.477	−2.9	1.598	−7.6	0.3327	0.3211	−3.5
⅞	1.679	1.679	0.0	1.839	−8.3	0.3808	0.3651	−4.1
1	——	1.913	——			——	0.4157	——
Avg			−9.9%		−9.2%			−5.0%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_1}{E}$	0.5602	0.5340	−4.7%	$\frac{L_1}{L_{03}}$	0.1167	0.1168	+0.1%
$\frac{L_2}{E}$	5.613	5.533	−1.4%	$\frac{L_2}{L_{03}}$	1.169	1.191	+1.9%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.
†Var. = Variation of calculated value (obtained by substitution in the theoretical equation with its correction factor) from the experimental value expressed in per cent of the experimental value.

TABLE 29.—Floor Lighting Data with "Corrected Calculated Values."

$L_{01} = 0,\ L_{02} = 0,\ L_{03} \neq 0;\ k_r = 0.9930,\ \rho_1 = 0.555,\ \rho_2 = 0.269,\ \rho_3 = 0.685$

h*	$f_3(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7500	0.09015	0.09232	+2.4%	0.1316	0.1347	+2.4%
0.8949	0.1024	0.1101	+7.5	0.1496	0.1608	+7.5
0.9527	0.1089	0.1183	+8.6	0.1590	0.1727	+8.6
1.0000	0.1151	0.1256	+9.1	0.1680	0.1833	+9.1

r*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	0.6685	——	——	——	——	0.09053	——
⅛	0.8030	0.7657	−4.7%	0.7846	−2.4%	0.1056	0.1036	−2.1%
¼	0.9318	0.8832	−5.2	——	——	0.1227	0.1196	−2.5
⅜	1.049	1.025	−2.3	——	——	0.1383	0.1388	+0.4
½	1.182	1.196	+1.2	1.186	+0.8	0.1556	0.1619	+4.0
⅝	1.352	1.399	+3.5	——	——	0.1780	0.1893	+6.3
¾	1.553	1.641	+5.7	——	——	0.2043	0.2221	+8.8
⅞	1.913	1.927	+0.7	1.916	+0.6	0.2516	0.2609	+3.7
1	——	2.267	——	——	——	——	0.3068	——
Avg			−0.2%		−0.3%			+2.7%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.7083	0.6312	−10.9%	$\frac{L_2}{L_{03}}$	0.09322	0.08599	−7.8%
$\frac{L_3}{E}$	8.473	8.176	−3.5%	$\frac{L_3}{L_{03}}$	1.115	1.105	−0.9%

TABLE 30.—Floor Lighting Data with "Corrected Calculated Values."

$L_{01} = 0,\ L_{02} = 0,\ L_{03} \neq 0;\ k_r = 0.7426,\ \rho_1 = 0.602,\ \rho_2 = 0.306,\ \rho_3 = 0.685$

h*	$f_3(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7500	0.1449	0.1565	+8.0%	0.2116	0.2285	+8.0%
0.8595	0.1523	0.1706	+12.0	0.2224	0.2491	+12.0
0.9368	0.1597	0.1815	+13.7	0.2332	0.2650	+13.7
1.0000	0.1699	0.1909	+13.4	0.2481	0.2787	+13.4

r*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp. Corr.	Corr. Calc.	Var.†
0	——	0.8880	——	——	——	——	0.2038	——
⅛	1.032	0.9629	−5.8%	0.9834	−3.1%	0.2081	0.2210	+6.2%
¼	1.129	1.048	−7.2	1.082	−3.1	0.2290	0.2405	+5.0
⅜	1.228	1.145	−6.8	1.182	−3.1	0.2501	0.2626	+5.0
½	1.325	1.253	−5.4	1.292	−3.0	0.2734	0.2875	+5.2
⅝	1.420	1.375	−3.2	1.418	−3.0	0.3001	0.3155	+5.1
¾	1.505	1.511	+0.4	1.561	−3.3	0.3303	0.3467	+5.0
⅞	1.663	1.663	0.0	1.767	−5.9	0.3739	0.3817	+3.1
1	——	1.833	——	——	——	——	0.4207	——
Avg			−4.0%		−3.3%			+4.8%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.7524	0.7432	−1.3%	$\frac{L_2}{L_{03}}$	0.1593	0.1717	+7.9%
$\frac{L_3}{E}$	5.539	5.173	−6.4%	$\frac{L_3}{L_{03}}$	1.170	1.186	+1.4%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.
†Var. = Variation of calculated value (obtained by substitution in the theoretical equation with its correction factor) from the experimental value expressed in per cent of the experimental value.

TABLE 31.—Floor Lighting Data with "Corrected Calculated Values."

$L_{01} = 0$, $L_{02} = 0$, $L_{03} \neq 0$; $k_r = 0.7426$, $\rho_1 = 0.555$, $\rho_2 = 0.269$, $\rho_3 = 0.685$

h'	$f_3(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7199	0.1049	0.1011	−3.6%	0.1531	0.1476	−3.6%
0.7500	0.1056	0.1037	−1.8	0.1541	0.1515	−1.7
0.8595	0.1121	0.1139	+1.6	0.1637	0.1663	+1.6
0.9368	0.1173	0.1219	+3.9	0.1712	0.1779	+3.9
1.0000	0.1221	0.1289	+5.6	0.1782	0.1882	+5.6

s'	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	0.8331	——	——	——	——	0.1268	——
⅛	0.9186	0.9209	+0.3%	0.8976	+2.6%	0.1415	0.1401	−1.0%
¼	0.9902	1.023	+3.3	——	——	0.1525	0.1556	+2.0
⅜	1.081	1.141	+5.6	——	——	0.1668	0.1736	+4.1
½	1.179	1.276	+8.2	1.205	+5.8	0.1817	0.1942	+6.9
⅝	1.296	1.431	+10.4	——	——	0.1999	0.2177	+8.9
¾	1.469	1.608	+9.5	——	——	0.2263	0.2446	+8.1
⅞	1.769	1.809	+2.3	1.766	+2.4	0.2735	0.2753	+1.0
1	——	2.038	——	——	——	——	0.3101	——
Avg			+5.7%		+3.6%			+4.3%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.8094	0.7864	−2.8%	$\frac{L_2}{L_{03}}$	0.1247	0.1205	−3.4%
$\frac{L_3}{E}$	7.250	7.300	+0.3%	$\frac{L_3}{L_{03}}$	1.122	1.109	−1.2%

TABLE 32.—Floor Lighting Data with "Corrected Calculated Values."

$L_{01} = 0$, $L_{02} = 0$, $L_{03} \neq 0$; $k_r = 0.5200$, $\rho_1 = 0.636$, $\rho_2 = 0.269$, $\rho_3 = 0.685$

h'	$f_3(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.7500	0.1495	0.1397	−6.6%	0.2183	0.2040	−6.6%
0.7993	0.1516	0.1439	−5.1	0.2214	0.2099	−5.2
0.9097	0.1572	0.1535	−2.4	0.2296	0.2240	−2.4
1.0000	0.1628	0.1619	−0.6	0.2377	0.2363	−0.6

s'	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp. Corr.	Corr. Calc.	Var.†
0	——	1.048	——	——	——	——	0.2147	——
⅛	1.054	1.116	+5.9%	1.011	+10.4%	0.2207	0.2286	+3.6%
¼	1.141	1.190	+4.3	1.116	+6.6	0.2436	0.2440	+0.2
⅜	1.215	1.273	+4.8	1.197	+6.3	0.2613	0.2608	−0.2
½	1.283	1.363	+6.2	1.273	+7.1	0.2779	0.2793	+0.5
⅝	1.381	1.462	+5.9	1.376	+6.2	0.3004	0.2995	−0.3
¾	1.447	1.569	+8.4	1.487	+5.5	0.3246	0.3215	−1.0
⅞	1.633	1.686	+3.2	1.681	+0.3	0.3670	0.3455	−5.9
1	——	1.814	——	——	——	——	0.3716	——
Avg			+5.6%		+6.1%			−0.4%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.7752	0.8633	+11.4%	$\frac{L_2}{L_{03}}$	0.1692	0.1780	+5.2%
$\frac{L_3}{E}$	5.328	5.620	+5.5%	$\frac{L_3}{L_{03}}$	1.163	1.150	−1.1%

TABLE 33.—Floor Lighting Data with "Corrected Calculated Values."

$L_{01} = 0,\ L_{02} = 0,\ L_{03} \neq 0;\ k_r = 0.5200,\ \rho_1 = 0.555,\ \rho_2 = 0.269,\ \rho_3 = 0.685$

h*	$f_h(h) = \rho_3 \frac{E(h)}{L_{03}}$			$\frac{E(h)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp.	Corr. Calc.	Var.†
0.5987	0.1213	0.1083	−10.7%	0.1771	0.1580	−10.8%
0.7500	0.1266	0.1171	−7.5	0.1849	0.1709	−7.6
0.7993	0.1298	0.1203	−7.3	0.1895	0.1756	−7.3
0.9097	0.1351	0.1278	−5.4	0.1973	0.1866	−5.4
1.0000	0.1377	0.1346	−2.3	0.2011	0.1965	−2.3

s*	$\frac{L_1(s)}{E}$			$\frac{L_1(s)}{E}$		$\frac{L_1(s)}{L_{03}}$		
	Exp.	Corr. Calc.	Var.†	Exp. Corr.	Var.†	Exp.	Corr. Calc.	Var.†
0	——	0.9979	——	——	——	——	0.1714	——
⅛	0.9771	1.058	+8.3%	——	——	0.1806	0.1818	+0.7%
¼	1.045	1.127	+7.8	1.048	+7.5%	0.1939	0.1938	+0.3
⅜	1.117	1.204	+7.8	——	——	0.2066	0.2067	0.0
½	1.198	1.290	+7.7	1.222	+5.6	0.2216	0.2216	0.0
⅝	1.301	1.385	+6.5	——	——	0.2406	0.2380	−1.1
¾	1.451	1.493	+2.8	1.454	+2.6	0.2682	0.2563	−4.4
⅞	1.696	1.609	−5.1	——	——	0.3136	0.2763	−11.9
1	——	1.739	——	——	——	——	0.2986	——
Avg			+5.1%		+5.2%			−2.3%

	Exp.	Corr. Calc.	Var.†		Exp.	Corr. Calc.	Var.†
$\frac{L_2}{E}$	0.8858	0.9420	+6.3%	$\frac{L_2}{L_{03}}$	0.1636	0.1638	−0.5%
$\frac{L_3}{E}$	0.153	0.309	+5.8%	$\frac{L_3}{L_{03}}$	1.137	1.116	−1.8%

*Distances are in terms of the ceiling height and are measured downward from the ceiling.

†Var. = Variation of calculated value (obtained by substitution in the theoretical equation with its correction factor) from the experimental value expressed in per cent of the experimental value.

Some Specifications for Industrial Lighting

In a Newspaper Printing Plant

IMPROVED employee morale and fewer errors have been two results of a lighting installation in a specific area of a specific industrial plant — the shop of the printing plant of the Antelope Valley Ledger-Gazette, Lancaster, Calif. L. M. Kelley, Lighting Consultant with Southern California Edison Co., met the challenge of providing high level illumination over the imposing stones of the shop, with sufficient general lighting in surrounding areas to avoid high-contrast conditions.

General lighting is provided by 2-lamp 96-inch 430 ma slimline units with upward component and egg-crate louvers. In the front part of the shop (48 feet wide by 42 feet long) which is used for small presses and Linotype machines, the fixtures are mounted on 12-foot centers in four continuous rows. Illumination level is 55 footcandles. In the narrower rear area (30 feet wide) the mounting height is the same and the units are on 10-foot centers in three continuous rows. Exposed rafters and trusses are painted white, walls are pastel green and floor is unpainted concrete. Presses and all other equipment are painted gray.

On all working surfaces in this area there is a minimum of 65 footcandles, as a result of arranging the equipment to coincide with fixture alignment. This arrangement was brought about through the interest of the shop foreman after he was shown the benefits of a well-engineered lighting job.

The customer's desire for complete mobility of imposing stones and type setting tables — so they could be set up and then wheeled to the press area — resulted in the design of a rack, which would hold the necessary type and under which the imposing and type setting tables could be rolled. Since this rack could be moved anywhere in the shop, the lighting fixture was mounted directly on it, rather than overhead.

Single-lamp 48-inch fluorescent strips with standard asymmetric reflectors are mounted, four under each type case, two feet above the stones. The units are then 1½ feet below eye level, shielded from the worker's view. Maintained illumination level on the imposing stones is 175 footcandles.

Brightness readings, shown below, are all within the limits recommended in the *IES Lighting Handbook*.

Brightnesses From the Worker's Position

louvers on overhead luminaires	250	ft-L
louvers on adjacent row of luminaires	165	ft-L
ceiling	15.5	ft-L
walls	24	ft-L
top of imposing table	32	ft-L
top of imposing forms:		
maximum	73	ft-L
minimum (inked)	12	ft-L
reflector on luminaire over imposing stones	36	ft-L
copy on imposing stones	100	ft-L

SPECIFICATIONS for lighting in industry may be for supplementary techniques for specific and limited areas or the provision of large-scale installations in areas with various visual tasks.

In a High-Bay Warehouse

ECONOMY of installation and operation; high quality lighting for inspection of polished metal sheets and micrometer gauging for size; and reduction in annoying shadows cast by large overhead cranes — these were the desired features in the high-bay lighting installation at Joseph T. Ryerson & Son's steel warehouse, Chicago.

In planning to meet these conditions, Vernon T. Kempf, Electrical Engineer for Ryerson's, first made an analysis of lighting systems, by filament, mercury, color-corrected mercury and slimline fluorescent, alone and in combination, for their characteristics as to economy, quality and distribution. On the results of this analysis and with the decision to use 440-volt line voltage, the slimline fluorescent was selected.

A total of 226 three-lamp open-end industrial fixtures are used in the 93,400 square foot areas, using 4500° White 96T12 lamps on 430 ma. Mounting height is 38 feet and spacing is on 20 by 20-foot centers, giving a spacing-to-mounting height ratio of 0.5. Three levels of illumination — 5, 10, and 15 footcandles — are controlled by a three-position selector switch, which energizes one, two or all three ballasts for each luminaire.

Maintenance and re-lamping is done from the crane platforms, with a disconnect switch at each truss to permit de-energizing the lights across the truss.

Results after installation were found to fulfill expectations of the initial analysis. The economies of the higher voltage system under conditions of this installation were evident in both labor and material. The installed cost per square foot was 19.8 cents and operating cost per year per square foot is 3.8 cents, at one cent per kilowatt-hour. This includes two cleanings per year.

The ratio of 0.5 for spacing to mounting height produced a measured variation in illumination of less than ½ footcandle over the area, with shadows from the crane reduced to an unannoying minimum.

Satisfaction with the results of this high-bay slimline installation in the Chicago warehouse led to the specification of a similar lighting system in the 156,000 square feet of the company's Milwaukee plant.

In an Aircraft Plant

THE NEW Rohr Aircraft plant at Riverside, Calif., is a factory of 200,000 square feet area, used mainly for fabricating sheet aluminum and stainless steel. Before the equipment layout for this new plant was known — indeed even before plant site was known — C. C. Clardy, the company's staff assistant in Plant Engineering, was handed the assignment of designing the lighting and power system for it.

A basic requirement was a high level of illumination, uniformly distributed over the entire area, which would be most suitable for all departments, regardless of where located. Sheet aluminum and stainless steel, having bright reflective surfaces, present a problem of glare. But the scribed lines on such sheets could be seen only by reflection of light from the bright sides of the lines.

Mercury lighting was considered the most effective for seeing fine detail in metals, and its use, in combination with some other source for color correction, was quickly decided upon. With the 480/277 volt power supply, fluorescent lighting was finally selected, after experimental tests, as the color correcting source to be used with the mercury. The ratio chosen was 80% mercury - 20% fluorescent.

Arrangement of the luminaires follows a pattern conforming to the roof trusses, which are spaced 20 feet on centers, crosswise of the building, with the members spaced 25 feet on centers lengthwise. Two rows of columns divide the factory into two 100-foot and one 50-foot bays. In this pattern, lighting units were mounted in a uniform spacing of 10 x 12½ feet. (George Twinning, of Quinton Engineers, Ltd., architects of the structure, is credited by the engineer for cooperation in the mounting of luminaires.)

Fixtures selected are: for mercury, prismatic glass reflectors, with upward component, double units using two 400-watt mercury lamps; and for the fluorescent, standard RLM steel porcelain-enameled 48-inch reflectors with two 85-watt lamps.

The factors on which these final plans were dependent were:

(1) Quality of illumination from the mercury-fluorescent combination, with the upward light supplied by the prismatic glass units.

(2) Average lighting levels well over 100 foot-candles.

(3) Use of the 488/277 power line for all lighting equipment, thereby eliminating duplicate transformers and long feeders.

A Study of High Intensity Light Sources

By STANLEY M. SEGAL

There are many commercial as well as military applications for the projection of powerful light beams. High intensity sources are necessary for this type of projection. This article summarizes a preliminary study of several high intensity sources. A more comprehensive approach in order to extend this work is contemplated for the near future.

COST AND PERFORMANCE are important considerations in the selection of a light source. Under performance are physical configuration, stability, power requisites, spectral characteristics and intensity per unit area. This study is concerned with the visible and near infrared portions of the spectrum.

Of a number of sources examined, seven are selected for discussion in this paper. The seven, photographs of which may be seen in Fig. 1, are:

1-kw mercury capillary in upper left corner,

1-kw high intensity mercury at top of second column with a 3-mm electrode separation,

3-kw tungsten — the large vertical envelope in the lower center,

1-kw high intensity xenon — first of the three vertical envelopes to the right of the tungsten; this xenon lamp has an 8-mm electrode separation,

35-ampere carbon pair at the top of the last column,

145-ampere therapeutic carbon pair,

190-ampere high intensity carbon with negative electrode disc.

The dimensions of the arcs and other sources discussed are indicated by a millimeter scale on Figs. 3, 4 and 5.

Fig. 2 is a plot of the spectral radiance curves obtained for the sources enumerated. At the bottom the wavelength is expressed in microns and at the left the ordinate scale is expressed in watts per steradian per square millimeter of source, per ten millimicron interval. The bottom curve is that of the 2870K CT tungsten ribbon filament lamp which was used as a standard by which the other curves were adjusted in ordinate. Directly above it is the curve for the 3-kw tungsten source, and next above, the 35-ampere projector carbon. The grouping of these three is merely one of convenience in order to use the ordinate scale reduced to one-tenth of the remaining curves. The middle set depicts an interesting contrast on the distribution of energy. The mercury capillary exhibits strong visible lines and the xenon shows strong line and band structure in the near infrared. The top set depicts the 190-ampere high intensity carbon arc, the 1-kw high intensity compact mercury arc, and the 145-ampere therapeutic carbon arc.

It can be observed that in any of these sources a relatively large amount of visible radiation must be accepted by the engineer who is solely interested in the near infrared. The mercury and xenon lamps, operating at high pressures, have continuous spectra in addition to the line spectra. The infrared line and band spectrum of the xenon, relatively

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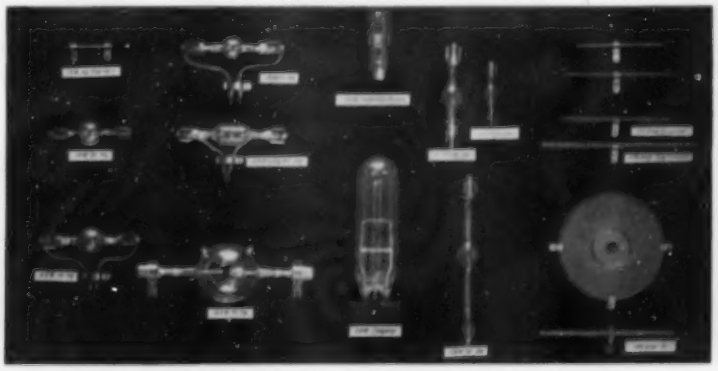


Figure 1. Display of light source items.

Photograph credits: Engineer Research and Development Laboratories, Fort Belvoir, Va.

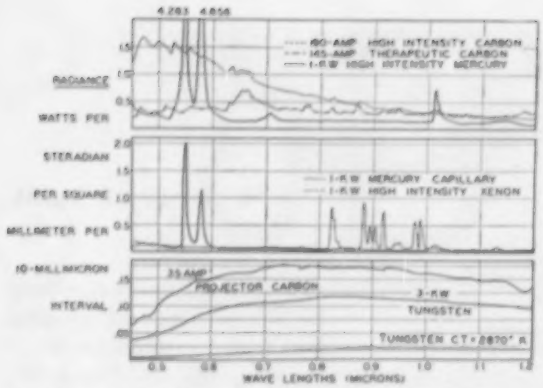
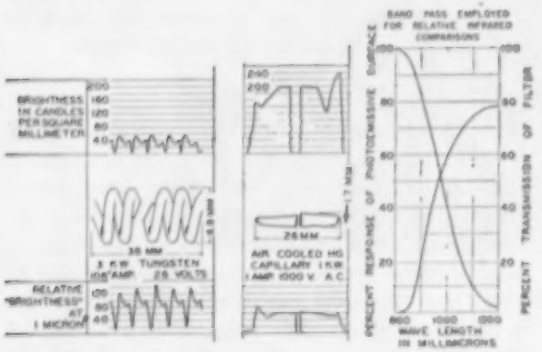


Figure 2. Spectral distribution of selected sources.


BRIGHTNESS IN CANDLES PER SQUARE MILLIMETER
RELATIVE "BRIGHTNESS" AT 1 MICRON
38 MM
3 KW TUNGSTEN
26 MM
AIR COOLED HG CAPILLARY 1 KW
BAND PASS EMPLOYED FOR RELATIVE INFRARED COMPARISONS
PERCENT RESPONSE OF PHOTOEMISSIVE SURFACE
PERCENT TRANSMISSION OF FILTER
WAVE LENGTH IN MILLIMICRONS

***XR7X26 Polaroid Dyed Plastic Sheet and RMA-Designated S-1 Response Photoconductivity Surface.**

Figure 3. Intensity per unit area and sketches of projected images of selected light sources; a definition of the receptor filter combination for the 1-micron study.

strong compared with the visible continuum, make this source particularly interesting to the infrared engineer who finds it necessary to filter out the visible radiation.

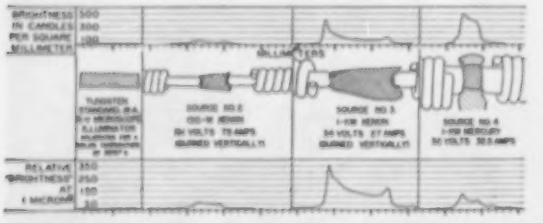
Fig. 3 is the first of three charts showing visual brightness of sources as well as relative infrared intensities per unit area. In the left center may be seen an enlarged drawing of the 3-kw tungsten filament. Above it is shown the brightness in candles per square millimeter in a longitudinal scan, and below it is shown the relative infrared intensity per unit area for the specific filter-receptor combination defined at the extreme right. Because the tungsten lamp, for which these data were obtained, was operated at an extremely high temperature for tungsten, it has a design life of only 10 hours and represents a high brightness for tungsten-filament sources. In the center is shown the same type of information for a 1-kw mercury capillary.

Fig. 4 shows, from left to right, a tungsten ribbon lamp with a color temperature of 2870K, a 150-watt high intensity xenon, one 1-kw high intensity xenon, and a 1-kw high intensity mercury. The significant point on this figure lies in the contrast between the last two sources. On the top scans it can be seen that the mercury excels in visible brightness, while on the bottom scans the xenon excels in infrared intensity per unit area.

Fig. 5 shows similar scans for a 35-ampere projector carbon, a 145-ampere therapeutic carbon, and a 190-ampere high intensity carbon and a zirconium open-air concentrated arc. The interesting thing here is that, while the high intensity 190-ampere carbon has the highest infrared intensity, it also has a much higher ratio of visible brightness than any of the other sources. The arc unit on which the zirconium measurements were made did not operate stably and that particular set of data may not represent optimum performance.

It is of interest to speculate on what all the foregoing data represent when the sources are used in a projector. A computation was made of the beam candlepowers and beam spreads which may be expected when each source is used in an 18-inch searchlight.

Fig. 6 is a bar chart showing peak, beam candlepowers calculated by assuming the source area to



***XR7X26 Polaroid Dyed Plastic Sheet and RMA-Designated S-1 Response Photoconductive Surface**

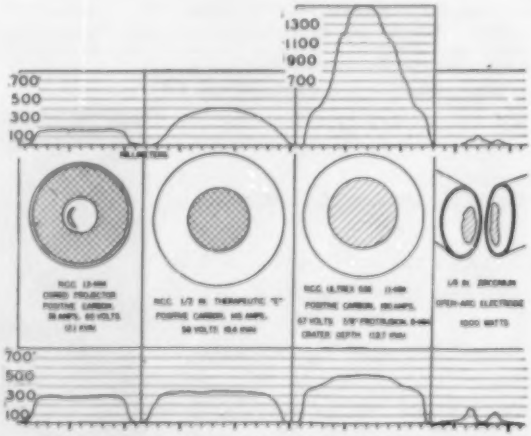


Figure 4 (left) and Figure 5 (right). Intensity per unit area and sketches of projected images of selected sources.

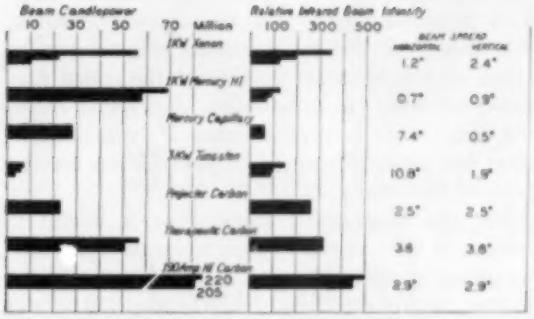


Figure 6. Calculated peak, average and minimum beam candlepowers in a given searchlight.

have uniformly maximum, average or minimum brightness over the entire area. The computations assumed a 19-inch diameter reflector with a 7⅞-inch focal length, a 90 per cent reflectivity and a 10 per cent shadowing. Similar information is shown for relative infrared beam intensities. The last two columns indicate the computed horizontal and vertical beam spreads. These computed beam candlepowers check very closely with field measurements made several months earlier. Spectral-wise, the projector carbon, the tungsten, and the xenon show good infrared ratios to visible output. Of these three the tungsten has the largest horizontal beam spread, the xenon has the least, and the projector carbon falls between the two. Future development may permit xenon lamps to be operated with the arc horizontal.

In quantity production the 1-kw xenon lamps will probably cost something over a hundred dollars apiece with about the same amount again for the controls which would weigh about fifty pounds and take up two cubic feet of space for 115-volt, 60-cycle operation. There would be a change in these values for power conversion and variation in design for use off a d-c power supply. Cost of the 1-kw mercury lamps would run about the same. The rated life of these two types of sources would run from approximately 30 to 300 hours depending upon the number of starts that were made. For mercurys, special ballasts and stand-by heaters would be required for instant starting and fast build-up to full power operation. From the standpoint of future development for higher beam candlepowers, there is relatively less to be expected for the tungstens. The 3-kw lamp studied, costing about twelve dollars, was operated at a very high color temperature for this type of light, and therefore has a rated life of about ten hours. However, no special auxiliary equipment would be involved. No special precautions would be involved either, as would be the case with the mercurys and xenons — which have very high internal pressures when hot. Xenon lamps require special precautions when cold. The carbons are very much in the picture. Costs for carbon arcs are from approximately twenty cents an hour for 2-kw projector carbons to five dollars an hour for the 12-kw, 190-ampere carbons.

Figs. 7, 8 and 9 show the arcs of high intensity 1-kw xenon, mercury and mercury capillary sources respectively.

The spectral distribution of radiance curves, Fig. 2, were obtained with a grating monochromator (500-mm focal length, 10 cm x 10 cm grating, 600 grooves/mm, blazed for first order 750 millimicrons), a light chopper, lead sulphide cell, amplifiers and recorder.

The recorded curves were corrected for linearity. Calibrations were made by running a record on a tungsten ribbon filament lamp operated at a color temperature of 2870K. An entrance slit of 2 mm was used and an exit slit of less than 0.1 mm.

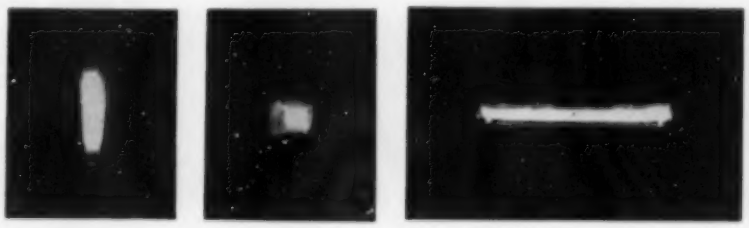
Ordinate units of radiance were computed in terms of watts per steradian per square millimeter of source per 10-millimicron interval. These were obtained as follows:

Spectral energy values for a 2870K tungsten lamp, similar in design to the calibrating lamp used at the Engineers Research and Development Laboratories, were published in the *Journal of the Optical Society of America* (February 1945, W. E. Forsythe, E. Q. Adams) in terms of microwatts falling on a square centimeter at a distance of one meter from a 100-candle lamp, in intervals of 100 Angstroms. A brightness determination was made of the ERDL tungsten lamp and factors were estab-

Figure 7 (at right). 1-kw high intensity compact xenon arc.

Figure 8 (center). 1-kw high intensity compact mercury arc.

Figure 9 (far right). 1-kw mercury capillary.



Example of Procedure for Obtaining Spectral Distribution Curves

Calibrating Lamp #1 had a spectral radiant intensity such that 100 candles caused 17.70 microwatts of energy to fall on one square centimeter at a distance of one meter, at 596 millimicrons, for a 10-millimicron interval. (*Journal of the Optical Society of America*, February 1945, p. 111.)

This amounted to 177,000 microwatts per steradian.

Since this value was based on 100 candles, and the source had an intensity, for one square millimeter, of 5.5 candles, the radiance became:

(5.5/100) 177 milliwatts per steradian per projected square millimeter of the source.

The radiance became 9.73 milliwatts/(steradian × sq. mm) for a 2870K tungsten in a 10-millimicron interval at 596 millimicrons.

Since the literature value of 17.70 was equivalent to the ERDL value of 9.73, all literature values were multiplied by 9.73/17.70 to get the milliwatt values to be plotted.

Furthermore, since Lamp #2 gave a relative brightness deflection of 56 at 596 millimicrons as against 11 for Lamp #1, all reduced record values of Lamp #2 were multiplied by the factor 9.73 (56/11) and reduced record values of Lamp #2 were obtained by dividing the record values of Lamp #2 at the various wavelengths by the record value of Lamp #2 at 596 mμ.

lished to convert into the brightness units. (See example.)

To adjust the ordinate values of the spectral radiance curves of the sources studied to those of the 2870K tungsten, the following procedure was followed: Measurements were made of brightness in four 10-millimicron bands wtih narrow band pass filters at 508, 596, 696, 815 millimicrons, on each source. This was done with a photomultiplier probe and a linear response "Photovolt" photometer; records were made of these relative intensities per unit area for each source at four points in order to enable the selection of a conveniently flat portion of the spectral scan for each adjustment. The circular area of the source measured had a diameter of 0.03 mm selected from the central portion of each source which was the portion also selected for focusing on the monochromator entrance slit. (The 3-kw tungsten source was the one exception in this procedure. The measurements were arbitrarily taken on the brightest portion of the coiled filament, throwing the distribution of radiance curve too high for the average radiance of the entire filament but representative of the distribution for the peak of the beam.)

For the longitudinal scans, Figs. 3, 4 and 5, images of the various sources were obtained with an optical system giving an exact magnification of thirty. A carefully measured lens stop (10.00 mm diameter) was used in order to apply the usual brightness formula.

$$B = E\,4\,S^2/T\,D^2$$

Where B equals brightness in candles per square millimeter, E equals illumination at the image in footcandles, S equals distance in feet between the lens and the image, T equals transmission of the lens and D equals diameter of the stop in millimeters. A barrier-layer cell corrected to match eye sensitivity stopped to ½-inch diameter and carefully baffled against stray light, was calibrated with a working standard lamp so that the deflections on a recorder indicated candles per square millimeter directly. An auxiliary multiscale linear response d-c amplifier was used. The cell surface exposed represented an area of 0.14 square millimeters of the source scanned at any instant. A synchronous motor was used to move the cell across the images at a speed of ½ inch per second, and the recorder chart moved with exactly the same speed. In this way it was merely necessary to overlay the charts on sketches of the images to obtain corresponding points on the curves and sources. This gave a highly efficient system for rapid evaluations. The infrared scans were taken in the same manner except that the ½-inch diameter stop was used with an especially selected photoconductive tube and a completely different auxiliary amplifier.

The accuracy of the foregoing measurements was calculated to be plus or minus 2 per cent for the longitudinal scans, and 4 per cent for the spectral distribution of radiance curves with an additional 15 per cent due to errors in the ordinate adjustment procedure involving the narrow band brightness measurements.

The author takes pleasure in acknowledging the encouragement and advice of Dr. Georg Hass and Mr. John A. Bartelt and the invaluable assistance of Sgt. John S. Sayer. Thanks are extended also to the National Carbon Co., the General Electric Co., the Westinghouse Electric Corp., and the Hanovia Chemical and Manufacturing Co. for the loan of materials and equipment.

Building-Top Lighting for Decorative Display

Lighted roof of office building attracts attention over New York's busy 34th Street, with famous Empire State Building towering in the background.

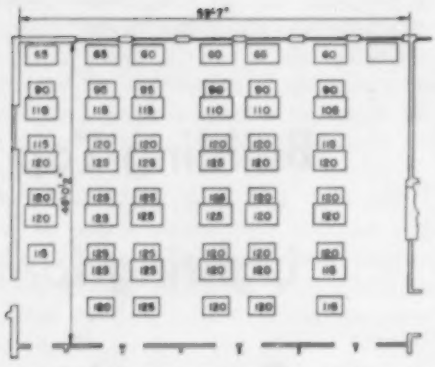
NEW YORK CITY's skyline has recently acquired a new decorative effect with the lighting of the roof of the 30-storey office building at 34th Street and Broadway.

Thirty-foot channels with premounted, specially-designed porcelain sockets are mounted on 16-inch centers vertically around the perimeter of the top of the building. These channels are made of six five-foot sections of turquoise green T12 1½-inch-diameter cold cathode lamps in 3-inch diameter clear Pyrex envelopes, sealed vacuum tight with special rubber gasketing and the porcelain housings at every five feet of channel. The continuous sections form 30 feet of lighting every 16 inches on three sides of the building.

The Pyrex envelopes are finished in an 180-degree arc with a specially prepared reflecting material, and the wall of light is diffused by louvers.

The whole system is operated in series with 240 ma cold cathode transformers. For maintenance the porcelain sockets are opened by unfastening four screw settings, and lamps are slipped out of the envelopes. The installation was designed in cooperation with the Webb and Knapp architects and Smith and Silverman, electrical engineers. Photo courtesy of Cold Cathode Lighting Corp., Long Island City, N. Y.

Close-up view shows louvers, lamps in continuous Pyrex envelopes, and porcelain housings.



Footcandle readings indicated in drawing are after one year's operation, and after cleaning. Levels before cleaning averaged 103 ft-c.

Performance Survey on a Luminous Ceiling Installation

By R. D. BURNHAM

A report on then-and-now performance of a luminous ceiling in a drafting office after one year's operation.

ABOUT TWO YEARS ago a luminous ceiling system was installed in the drafting room of the engineering building of General Petroleum Corporation, Torrence, California. Two lighting surveys have since been made of the installation, one initially, and another about a year later. The results of these surveys turn up some interesting figures relating to the maintenance of translucent ceilings. While this survey does not settle once and for all how often and how much it costs to maintain a lighting system of this type, it may offer an interesting "for instance."

The room is approximately 46 ft by 60 ft. Five windows are shielded with venetian blinds. Plastered walls were painted light green with reflectances of 73 per cent. The floor was of light gray asphalt tile with a reflectance of 28 per cent. Partitions have a reflectance of 41 per cent.

In this room, planned to hold brightness contrasts at a minimum, seven rows of luminous diffusers six feet wide were installed 10 ft 2 inches above the floor. Suspension was from electrical channels on the ceiling carrying 168 fluorescent lamps, 96T12, 3500 white. The rows were spaced 16 inches apart.

The plenum cavity above the diffusers has the same reflectance as the side walls, 73 per cent. The original survey made by Glen E. Hutcheraft and J. N. Robertson, registered electrical engineers, stated: "The efficiency of the installation would be raised even higher if the plenum surface were covered with a higher reflectancy paint." The acrylic corrugated diffusers are standard translucent white, .080" thick.

The original surveys showed a light intensity of 122 footcandles maintained at 3 ft, 6 inches above the floor. This was arrived at by readings taken between April 2, 1953 and July 22, 1953. Brightness readings on the lower surface of the diffusers was 303 footlamberts, walls 64, floor 36, and the non-luminous surfaces (3 ft wide) between the diffusers averaged 38 footlamberts. The brightness ratio of less than 8 to 1 between the diffusers and the non-luminous strips was reported as "pleasing" because of the proportions and arrangement.

Effect of Cleaning—On May 16, 1954 the plastic diffusers were removed and wiped with Merix 79 at a total cost of $160. No lamps were replaced.

A reading taken May 17, 1954 after this cleaning showed an average intensity of 112 footcandles.

AUTHOR: P. W. Wakefield Brass Co., Vermilion, Ohio.

TELECAST

LIGHTING NEWS OF CURRENT INTEREST

C.I.E. Delegates Hold Final Pre-Zurich Meeting

A meeting of the delegates to the 1955 Sessions of the C.I.E. was held in the Board Room of the Electrical Association of Philadelphia, on March 14. Present were 19 of the 30 accredited delegates including International President Ward Harrison, Honorary Secretary Carl Atherton, and eight other U.S.N.C. members.

Each delegate was presented with a specially designed loosleaf note book for use in his work. Definite committee assignments were made and the activities of the various technical committees were discussed in detail.

The sessions will be held in Zurich, Switzerland, June 13 to 23. Many administrative meetings will be held during the previous week in order to give the officers an opportunity to attend the regular scheduled technical meetings. This will be the largest delegation ever to represent the United States at an overseas meeting.

The officers of the United States National Committee are: President, Arthur A. Brainerd; Vice-President, Willard C. Brown; Secretary, Louis E. Barbrow; Treasurer, Theo. D. Wakefield.

Atlanta Residence Lighting Forum Sums Up Active Year

Four meetings of unusual interest made up this year's program of the Atlanta Residence Lighting Forum of the Georgia Section, I.E.S., Mrs. Mary Bush, Chairman.

The first Forum meeting, last Fall, was a joint one with the Georgia Section. An attendance of 89 turned out to hear Mr. E. W. Commery, Director of the Residential Lighting Development Section of General Electric's Lamp Division, who spoke on "Lighting Design and Activities for the Home — Yesterday, Today and Tomorrow." Paul Harrison, Georgia Section Chairman, presided, and Mr. Commery was introduced by Forum Chairman Mrs. Bush.

Featured at the second meeting was a presentation, with slides and equipment, by Miss Myrtle Fahsbender, Director of Residential Lighting, Westinghouse Lamp Division. Miss Fahsbender's topic was "Coordinating Light with Residential Architecture and Decor." She also demonstrated new fabrics that are being developed for better light reflectance.

At the January meeting, Judd Lough, of the Holophane Company, gave a demonstration on the many ways of controlling light.

The final meeting, March 14, was a Garden Lighting Workshop, as a prelude to a garden lighting project. General principles of garden lighting were discussed and illustrations of installations shown.

There was an average attendance of 48 at these Forum meetings, which were held at the YMCA and at the Sara Holcombe Tea Room, in Atlanta.

Certified Lighting Bureaus Announced in Three More Cities

Electrical groups in San Francisco and San Diego, Calif., and in Cincinnati, Ohio, have announced the intention of inaugurating programs of the Certified Lighting Bureau.

In San Francisco, the operation was inaugurated by the Northern California Electrical Bureau, with training classes beginning April 19. In San Diego County, the program is being sponsored by the Electrical Contractors Division, Bureau of Home Appliances of San Diego County. The training sessions are beginning in May.

The Cincinnati operation, sponsored by the Cincinnati Electrical Association, will cover the 2,500 mile area of Butler, Warren, Hamilton, Clermont, Boone, Kenton, Campbell, Grant and Brown Counties,

EXECUTIVE Committee for the 1955 IES National Technical Conference held a meeting March 11, at the General Electric Lighting Institute. Committee Chairmen shown in the photo are: l. to r., seated, T. D. Wakefield, Printed Publicity; Mrs. F. E. Mueller, Ladies Reception; C. N. Lanpp, Conference Committee; Mrs. W. H. Kahler, Ladies Reception; F. I. Wilson, Entertainment; C. L. Amick, Conference Executive Committee; standing, E. I. Creed, Registration and Reception; Theodore Ake, Attendance; M. E. Keck, Display and Decorations; J. J. Neidhart, Local Publicity.

Here and There With I.E.S. Members

New Orleans Section winners of the "My Most Interesting Lighting Job Contest" were announced at a recent Section meeting. In this photo, from left to right are: Conrad Berdon, Section Secretary; Tom Melady, second prize winner; Arthur Levy, Section Chairman; George Schroeder, Jr., first prize winner; Quintard Wiggins, Jr., Contest Chairman; and Pierre Bagur, third prize winner.

First prize winner, W. J. Lind (right) receives the check from British Columbia Section Chairman T. H. Doherty. Other winners in this Section's MMILJ Contest are J. Gilbreath, second prize and J. Baxter, third prize.

Winners in the Southern California Section's MMILJ Contest were selected at the Section's March 2 meeting. In the usual order are: third place winner, R. B. Hatfield; second, Laddie N. Tilson, and first prize winner, G. L. Dovey.

A new kind of program was tried at the February meeting of the Milwaukee Section Study Club. Dubbed the "Most Theoretical Lighting Contest" the problem was to design a lighting system for a theoretical office area, with no limitations as to cost, fixtures available or present lighting system. At left Arthur A. Wanty, consulting engineer, demonstrates his solution; and at right, Clarence Knoerr, electrical contractor, a sketch of his treatment. This interesting program was the idea of Study Club Chairman Robert VandenBoom.

Ohio. Detailed preparation of the program is scheduled for the Spring and Summer and the inauguration of activities will be in the Fall.

Industrial Lighting — Topic Of Extension Clinic

A clinic on Industrial Lighting was presented April 12, in Metuchen, N. J., under the guidance of M. S. Ewing, I.E.S. Local Representative in New Brunswick. Directed at Plant, Production, Project and Maintenance Engineers in the area, the program presented was determined from a sampling of opinions of plant people. Topics and speakers were:

Light Sources and Equipment — John McDougall, Lamp Applications Engineer, General Electric Co., Newark, N. J.
Electrical Distribution Systems—L. F. Stone, Chief Engineer, Apparatus Dept., General Electric Co., Newark, N. J.
Maintenance of Lighting Systems — J. M. Petruska, Supt. of Maintenance, Wright Aeronautical Division, Wood-Ridge, N. J.
General Industrial Lighting Techniques—John Hamilton, Lighting Engineer, Day-Brite Lighting, Inc., New York, N. Y.

Adequate Home Wiring Gains in Acceptance

Recent investigations by the National Electrical Contractors Association have indicated that many cities throughout the country are passing ordinances making 100-ampere electric service entrance equipment a minimum requirement for all homes having up to 3,000 square feet floor area. This recommendation, contained in the Residential Wiring Handbook recently published by the Industry Committee on Interior Wiring Design, will enhance the opportunity for most homes to have the advantages of better lighting as well as other uses of electrical energy.

Spokane, Washington, has gone even further, in revising its home building ordinance so that all houses having over 500 square feet floor area are required to install service entrance devices having a 200-ampere rating.

Winter Lighting Conference Sponsored by Cornhusker Chapter

An attendance of 119 proclaimed the success of the Winter Lighting Conference of the Cornhusker Chapter, I.E.S., held January 28, at the Rome Hotel in Omaha, Nebraska. The conference was called to order by Chapter Chairman R. W. Gibb, of Omaha Public Power District; the opening remarks were made by Program Chairman C. P. Hass, of the General Electric Co.

(Continued on page 9A)

LIGHTING CALENDAR

Society Events

May 19-20, 1955 — East Central Regional Conference, Abraham Lincoln Hotel, Reading, Pa.

June 8, 1955—Meeting of I.E.S. Council, Lake George, New York.

June 10-11, 1955 — Northeastern Regional Conference, Ft. William Henry Hotel, Lake George, N. Y.

September 12-16, 1955 — Illuminating Engineering Society, National Technical Conference, Hotel Statler, Cleveland, Ohio.

Industry Events

April 17-22, 1955 — Society of Motion Picture and Television Engineers, 77th Semiannual Convention, The Drake Hotel, Chicago, Ill.

April 18-21, 1955 — The American Society of Mechanical Engineers, Spring Meeting, Lord Baltimore Hotel, Baltimore, Md.

April 25-27, 1955 — National Association of Lighting Maintenance Contractors, Annual Conference, Henry Grady Hotel, Atlanta, Ga.

May 4-6, 1955—American Institute of Electrical Engineers, Middle Eastern District, Deshler-Hilton Hotel, Columbus, Ohio.

May 10-12, 1955 — Chicago Electrical Industry Show, Conrad Hilton Hotel, Chicago, Ill.

May 11-13, 1955 — Pacific Coast Electrical Association, Inc., Annual Convention, Palace Hotel, San Francisco, Calif.

May 12-13, 1955 — Public Utilities Advertising Association, Annual National Convention, Sheraton Hotel, Chicago, Ill.

May 22-25, 1955 — National Association Electrical Distributors, 47th Annual Convention, Conrad Hilton Hotel, Chicago, Ill.

June 12-15, 1955 — Western Plant Maintenance and Engineering Show, Pan Pacific Auditorium, Los Angeles, Calif.

June 13-16, 1955 — Edison Electric Institute, Annual Convention, Los Angeles, Calif.

June 13-22, 1955 — International Commission on Illumination (CIE), 13th Session, Zurich, Switzerland.

June 20-24, 1955 — American Society for Engineering Education, Pennsylvania State University, State College, Pa.

June 26 - July 1, 1955 — American Society for Testing Materials, 58th Annual Meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.

June 27 - July 1, 1955 — American Institute of Electrical Engineers, Summer General Meeting, New Ocean House, Swampscott, Mass.

August 15-19, 1955 — American Institute of Electrical Engineers, Pacific General Meeting, Butte, Montana.

September 25-28, 1955 — National Association of Electrical Distributors, Annual Convention, Pacific Zone, Empress Hotel, Victoria, B. C.

September 27-29, 1955 — Electrical Progress Show, Convention Hall, Philadelphia, Pa.

October 1, 1955 (Tentative) — Institute of Traffic Engineers, 26th Annual Meeting, Pittsburgh, Pa.

October 3-5, 1955—National Electronics Conference, Hotel Sherman, Chicago, Ill.

October 3-7, 1955 — Society of Motion Picture and Television Engineers, 78th Semiannual Convention, Lake Placid Club, Essex County, N. Y.

October 3-7, 1955 — American Institute of Electrical Engineers (Fall General Meeting), Morrison Hotel, Chicago, Ill.

October 5-7, 1955 — Canadian Electrical Manufacturers Association (11th Annual Meeting), Sheraton-Brock Hotel, Niagara Falls, Ontario, Canada.

October 11-14, 1955 — National Electrical Industries Show, 69th Regiment Armory, New York, N. Y.

October 17-21, 1955 — National Safety Council, 43rd National Safety Congress & Exposition, Chicago, Ill.

October 24-26, 1955 — 37th Annual Meeting and Sixth National Conference on Standards, American Standards Association, Washington, D. C.

October 30, 1955—Week of—National Electrical Contractors Association, Waldorf-Astoria, New York, N. Y.

November 1-3, 1955 — Fifth Industrial Electric Exposition, Hotel Wm. Penn, Pittsburgh, Pa.

November 2-5, 1955 — National Electrical Contractors Association, Annual Convention, Waldorf-Astoria Hotel, New York, N. Y.

November 14-18, 1955 — National Electrical Manufacturers Association, Annual Meeting, Traymore Hotel, Atlantic City, N. J.

November 14-18, 1955 — Chicago Exposition & Power and Mechanical Engineers ASME Chicago Coliseum, Chicago, Ill.

A report on the I.E.S. Council meeting which was held April 13 in Phoenix, Arizona, will appear in the June issue of IE.

Sinclair uses Day-Brite lighting

gets "See-ability" at its best

The new 10-story Sinclair Oil Building in Chicago is completely lighted with Day-Brite recessed Troffers*—nearly 4,000 of them!

The reason Sinclair uses these popular Day-Brite lighting fixtures is evident from the photograph. They provide lighting at its best—give employes work-level visibility without eye strain; boosts morale and efficiency.

The Day-Brite Troffer is a low-brightness, high-efficiency fixture. Can be easily and economically flush mounted in any type ceiling. Can be supplied for slimline or rapid-start lamps.

SEE! EXAMINE and COMPARE Day-Brite with any competitive fixture. Then make your choice on the basis of the evidence.

**Installed by Fishbach, Moore & Morrissey, Inc., for John W. Galbreath & Co., Inc.*

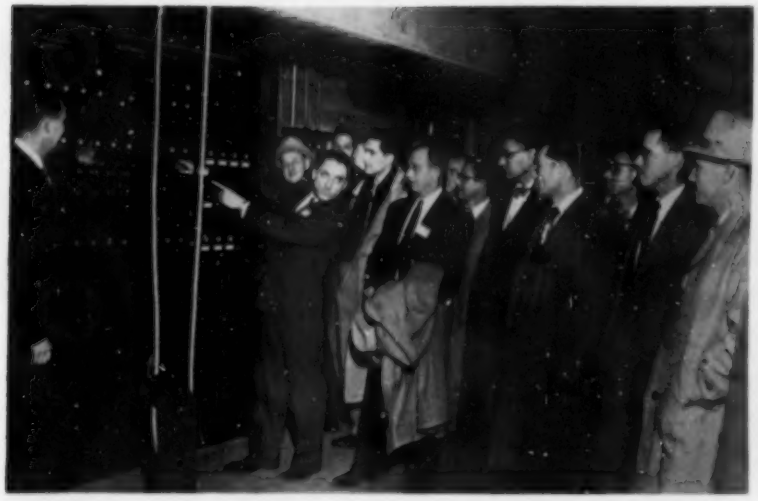
call your Day-Brite representative

5432

"DECIDEDLY BETTER"
DAY-BRITE
Lighting Fixtures

Day-Brite Lighting, Inc., 5432 Bulwer Ave., St. Louis 7, Missouri.
In Canada: Amalgamated Electric Corp., Ltd., Toronto 6, Ontario.

NATION'S LARGEST MANUFACTURER OF COMMERCIAL AND INDUSTRIAL LIGHTING EQUIPMENT



TOUR of Omaha, Nebraska's new city auditorium was a part of the Winter Lighting Conference of the Cornhusker Chapter, January 28. Here Professor Theodore Fuchs, Northwestern University, demonstrates the panel board controlling the lighting.

(*Continued from page 7A*)

The program of technical papers included:

Street Lighting — Warren H. Edman, Holophane Co., Inc., Newark, Ohio
Street Re-Lighting—The Kansas City Story — P. C. Box, Street Lighting Engineer, Kansas City, Mo.
Lighting Tone — J. S. Frizzell, Pittsburgh Reflector Co., Pittsburgh, Pa.
"My Most Interesting Lighting Job" Contest — D. L. Donelson, Chairman, and contestants.
Stage and Auditorium Lighting — Professor Theodore Fuchs, Northwestern University, Chicago.

Professor Fuchs conducted the group on a tour of the new Omaha City Auditorium, which was followed by a social hour and dinner.

Michigan Section Takes Part In Better Vision Week

As proclaimed by Governor G. Mennen Williams, the week of March 6-12 was recognized as the first annual Better Vision Week. The Michigan Section of I.E.S. held a well-publicized and well-attended meeting March 8, with a program fitting in with the Week.

The program started with a sound-and-color movie, "A Case for Color," presented by R. O. Bradley, Maintenance Sales Supervisor of the Finishes Division, E. I. duPont de Nemours. Following this, Dr. H. Richard Blackwell, Director of the Visual Research Laboratory at the University of Michigan, spoke on "Illumination for the Visually Handicapped." Duncan Preston, Detroit Edison Co., served as program chairman.

C.L.I. Celebrates Silver Anniversary

Twenty-five years of service to the lighting industry were commemorated April 11, by the Chicago Lighting Institute, at a luncheon meeting at the Palmer House in Chicago. David P. Wood, President of the Institute, presided.

The program began with an address by Lawrence B. Sizer, Vice-President, Public Relations Division of Marshall Field and Company, who spoke on "A Little Light on Giving the Lady What She Wants." Carl W. Zersen, Managing Director of the Institute then gave the operating report, "Highlights — 1930-1955."

Another feature of the program was the presentation by Mr. Wood of the C.L.I. Citations to Blair Plimpton, Superintendent of Schools and Russel Miller, Superintendent of Buildings and Grounds, Board of Education, Park Ridge, Ill.

Attendance was 180.

School Lighting Clinic Continues Chicago Series

A program on school lighting, planned for school administrators, architects, eye and health specialists, electrical contractors, and lighting engineers, was sponsored April 21, as a joint activity of the Chicago Lighting Institute and the Chicago Section of I.E.S.

The clinic opened with registration and inspection of the Institute's demonstration rooms, followed by a Welcome from Managing Director Carl W. Zersen. The program consisted of:

MORNING

Chairman — M. M. Cruft, Administrative Assistant and Building Consultant to the Superintendent of Public Instruction, State of Illinois, Springfield, Ill.

Opening Remarks — Blair Plimpton, Superintendent of Schools, Park Ridge, Ill.
Seeing Needs in the Classroom — R. D. Bradley, Director of Engineering, Day-Brite Lighting, Inc., St. Louis, Mo.

(*Continued on page 10A*)

INFORMAL discussion group after the March 8 meeting of the Michigan Section of I.E.S. was made up of, from left to right: Floyd Sell, Section Chairman; Vern Winn; George Evans; H. Richard Blackwell; G. R. Clover, and Frank H. Clingan.

CHARTER of Section status for the Utah Section, I.E.S., is handed to Chairman Marvin Dansie, left, by immediate Past-Chairman Dale Brown, as Section members Leo Hansen and Donald Dyrenforth look on. The ceremony took place on January 26, at a luncheon meeting at Salt Lake City's Newhouse Hotel.

(*Continued from page 9A*)

Modern Architectural Trends — John H. Wanaka, School Lighting Consultant, Wisconsin Electric Power Co., Milwaukee, Wis.

Environmental Features in the Schoolroom — Lucille Knoche, Lucille Knoche Associates, Chicago, Ill.

AFTERNOON

Chairman — Dr. Henry Boettcher, Superintendent of Lutheran High School Association, Chicago, Ill.

Applied Lighting Systems:
(a) Incandescent — David H. Mason, Illuminating Engineer, Mason & Basedow, Chicago, Ill.
(b) Fluorescent — Richard M. Smart, Regional Illuminating Engineer, Sylvania Electric Products, Inc., Chicago, Ill.
(c) Large-Area Types — James C. Weeks, Lighting Sales Engineer, Westinghouse Electric Corp., Chicago, Ill.

Making the Most of Your School Lighting Dollar — Ben F. Avery, District Lighting Engineer, General Electric Co., Chicago, Ill.

Quiz Panel and Summary — Professor Harry Horn, Department of Electrical Engineering, University of Illinois, Urbana, Ill.

Audience participation was invited, and received, in the quiz panel, with Professor Horn as discussion leader.

Chairman of the Conference Planning Committee was Ralph R. Lusk, Illuminating Engineer with Commonwealth Edison Co.; Co-Chairman, William Mescher, Public Service Co.

A combined fee of $7.00 covered both registration for the clinic and luncheon at the Y.W.C.A. The sessions were held at the Lighting Institute.

UNESCO Coupon Scheme for Membership Subscriptions

Information circular #11, recently issued by the United Nations Educational, Scientific and Cultural Organization, reaffirms the continuation of the system of UNESCO coupons for foreign purchase of publications in the fields of education, science and culture. Also authorized is the use of these coupons for membership subscriptions to learned societies, when such subscriptions are mainly a means of obtaining the publications of the society. I.E.S. participates in this program by accepting these coupons as payment for foreign purchase of the Society's publications.

ABOUT PEOPLE

Edward C. Huerkamp has been named manager of the lighting division of Westinghouse Electric Corp., to succeed **Burt S. Burke**, who has been appointed district manager for the company's North Texas district.

Warren Edman, Manager of Street Lighting for Holophane Co., Inc., has been appointed Vice-President in Charge of Street Lighting. His base of operations will remain at Newark, Ohio, where the factory and Engineering Center are located.

The appointment of **Lawrence R. Sweetser** as manager of the applications laboratory of the Lighting Division of Sylvania Electric Products, Inc., has been announced. Mr. Sweetser, who has been with Sylvania since 1943, will have his office at the Division's headquarters in Salem, Mass.

Appointment of **Clinton W. Meury** to the position of Manager of Nela Properties of General Electric's Lamp Division, with headquarters at Nela Park, has been announced. Nela Properties operates under the supervision of the Miniature Lamp Department, of which **K. G. Reider** is general manager. Mr. Meury succeeds **Hollis L. Townsend**, who retired April 1 under provisions of the company's optional pension plan.

Aldo M. deBellis, assistant electrical engineer, Consolidated Edison Co., New York, has been awarded the 1954 Lamme Medal by the American Institute of Electrical Engineers. The Medal will be presented during the Summer Meeting of the Institute at Swampscott, Mass., June 27-July 1.

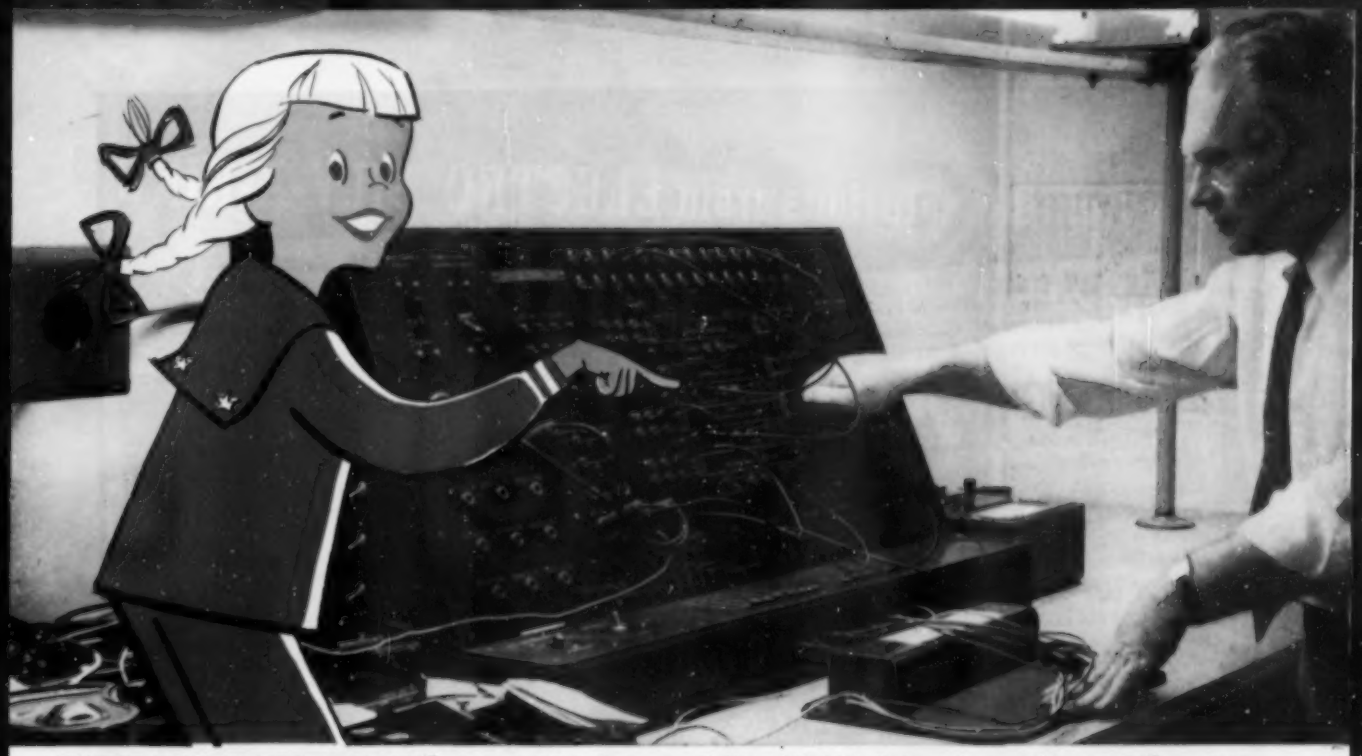
Joseph A. Schneller, Director of Sales for Lighting Products Inc., Highland Park, Ill., has been elected to the position of Vice-President in Charge of Sales

Kopp Glass, Inc, has announced the appointment of **Willard A. Provost** as assistant sales manager, and of **John E. Bright** as manager of the New York Sales Office. Mr. Provost, who previously was eastern sales manager, will have headquarters at the company's Swissvale, Pa., plant. Mr. Bright will make his New York area office in East Orange, N. J.

The Edwin F. Guth Co., St. Louis, Mo., has named the firm of Tru-Lite Limited as distributors in Canada. Tru-Lite, which is headed by **O. M. Trudel**, is located at 824 Notre Dame St., W., Montreal, Que.

At a recent meeting of stockholders of Consolidated Gas Electric Light and Power Co. of Baltimore, **J. Pierre Bernard** was elected a director, to fill the vacancy created by the death of **William Schmidt, Jr.**, and the fourteen incumbent directors were reelected. The stockholders also approved a charter amendment changing the company's name to Baltimore Gas and Electric Co. Following this meeting, the Board of Directors elected **Charles P. Crane** chairman of the board in addition to renaming him president. **Mason C. Albrittain** was elected vice president and general sales manager.

(*Continued on page 13A*)



EXCLUSIVE ELECTRICAL TESTS provide 100% check of G-E ballasts assuring you of rated output from ballast to lamp. When you buy or specify General Electric ballasts, you're assured of up to 30% more light and up to 50% longer lamp life. This helps you save lighting dollars.

Flora* shows you why . . .

G-E Lamp-matched Ballasts Give You Up to 50% More Lamp Life, 30% More Light

The life and light output ratings of fluorescent lamps are based on their use with ballasts which provide the required operating characteristics. General Electric lamp-matched ballasts meet all lamp requirements; in many ways they exceed prescribed lamp and CBM specifications.

An indication of the importance of the ballast to more economical lighting is given in a report issued by the General Electric Lamp Division which reads in part: "Tests indicate that ballasts which deliver improper values reduce lamp life by as much as 50% and light output by as much as 30%."

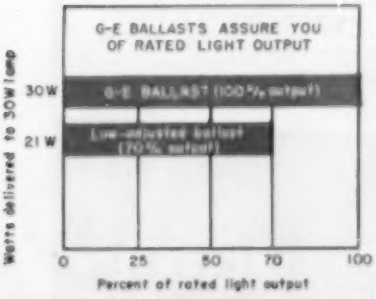
To fluorescent lighting users, this means G-E ballasts can save thousands of dollars in lighting costs.

Next time you specify equipment for a fluorescent lighting installation, make sure you get the best . . . specify General Electric lamp-matched ballasts.

A G-E ballast tag or sticker on your fixture is proof that it's equipped with the best in ballasts. It's the easy way to be certain. For further information on G-E ballasts, write Section 401-14, General Electric Company, Schenectady 5, New York.

*Miss Fluorescent Ballast, G.E.'s ballast mascot.

Copyright 1955, General Electric Company.



RESULTS OF A SPECIFIC TEST show that light output can be reduced by as much as 30% when ballasts do not deliver specified electrical values. Specify G.E. for rated output.

Five more reasons why

GENERAL ELECTRIC IS YOUR BEST BALLAST VALUE

- **EXCLUSIVE SOUND RATING SYSTEM**
- **SUPERIOR QUALITY CONTROL**
- **LONGER BALLAST LIFE**
- **PROVED PRODUCT LEADERSHIP**
- **COMPLETE CUSTOMER SERVICES**

Progress Is Our Most Important Product

GENERAL ELECTRIC

new lighting solutions from ELECTRO SILV-A-KING

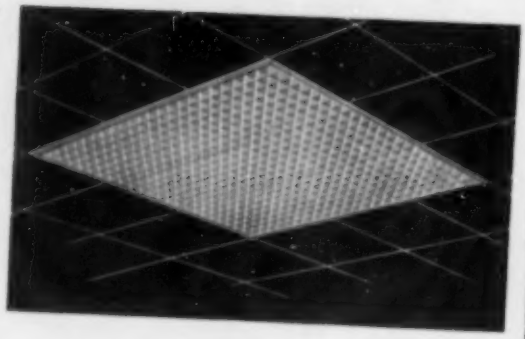
MODULAR SQUARES

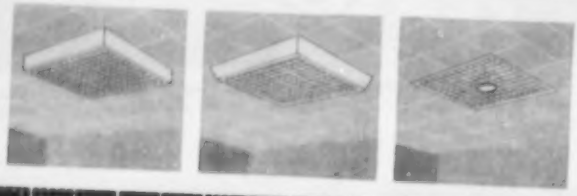
PROBLEM *How to create larger light source areas more economically . . . and how to utilize the same basic fixture throughout the installation.*

BAYLITE *. . . in modular squares from 2' x 2' to 5' x 5' for surface or recessed mounting, slimline or fluorescent.*

Lighting patterns take on new flexibility with versatile BAYLITES. They can be used individually, in continuous runs, or grouped to create a "louver-all" appearance for large light source areas with a minimum number of fixtures.

BAYLITE units can be recessed or surface mounted . . . and the extremely wide range of possible light intensities allow their use throughout an entire installation so as to achieve a pleasing, uniform effect.





ELECTRO SILV-A-KING BAYLITES are available in several models or to your specifications.

- 2' x 2', 2' x 4', 4' x 4', 5' x 5'.
- Four, Six, Eight or Ten Lamps • Metal sides or skirts
- Gimbal Ring spots available for PAR-38 lamp
- 35° x 35° shielding—with standard metal louver (Plastic available)
- Rapid Start • Standard Fluorescent • Slimline

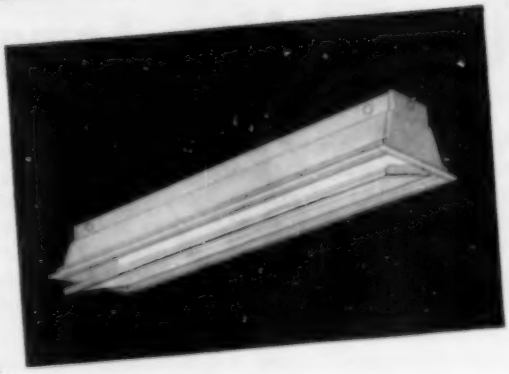
TM TROFFER SERIES

PROBLEM *How to improve the aesthetic qualities of Troffer lighting with a reduction in installation and servicing costs.*

Exclusive

magic frame

TROFFERS *. . . eliminate all exposed, unsightly door screws and latches. Exclusive simplified installation provides "Speedy Latches" in wireway channel for efficient and simple hanging. All electrical components are contained on a removable chained cover.*



"MAGIC FRAME" Troffers have no unsightly protuberances to disturb the trim lines of the fixture. Doors lock by gravity, hinge on two concealed pivots for quick maintenance. Completely removable by merely lifting and shifting. For installation, maintenance or removal of the door, there are no screws to loosen, remove or lose . . . doors are interchangeable into any like Magic Frame fixture.

"Magic Frame" Troffers are available with all types of flat glass and plastic diffusers such as: ALBA-LITE, FOTA-LITE, CRYSTAL-LITE, TWINLENS, P4 DIAMOND PATTERN PLEXIGLAS. 2-ft., 4-ft., 5-ft., 8-ft., lengths. Rapid Start • Standard Fluorescent • Slimline.

Write for the name of the ELECTRO SILV-A-KING district manager near you . . . and new Specification Data Catalog

ELECTRO SILV-A-KING CORPORATION

1535 S. Paulina Street, Chicago 8, Ill. • Spruce and Water Streets, Reading, Pa.

(Continued from page 10A)

George H. Stickney, who has suffered some illness recently, is happily reported on the mend. Mr. Stickney, who has been a member of I.E.S. since 1906 (Charter Member) is at his home in Daytona Beach, Fla.; postal address P. O. Box 5056.

Jefferson Electric Co., has announced the appointment of **Henry A. Wallis** as midwest district sales manager, with headquarters in the home office in Bellwood, Ill. The company has also named **Lyons O. Dugan** as sales manager for the western district with offices in Los Angeles, Calif. Jefferson has also promoted **Hubert J. Powell** to the position of senior salesman with his headquarters in Charlotte, N. C.

William E. Smith has been elected vice president in charge of purchasing of Mitchell Manufacturing Co., Chicago. Mr. Smith, who has been with Mitchell since 1946 as director of purchasing, will supervise all purchasing activities for the company.

Robert L. Kuschwa has been appointed supervisor of fixture sales for the Chicago area by the Lighting Division of Sylvania Electric Products Inc. with his offices at the company's sales office in Melrose Park, Ill.

Kuhlman Electric Co., Bay City, Mich., has named **William T. Sackett, Jr.**, as Manager of Research. Prior to this appointment, Mr. Sackett spent five years as a Senior Engineer and Assistant Chief of the Electrical Engineering Division of the Battelle Memorial Institute, Columbus, Ohio.

H. E. Williams Products Co., Electrical Division, in Carthage, Mo., has appointed **Roger E. Bessmer** as fluorescent fixture representative in the states of Missouri, Kansas, Iowa and Nebraska. Mr. Bessmer has his office at 1217 W. 25th Street Terrace, Independence, Mo.

OBITUARY

Fred E. Harroff, former vice-president of the General Electric Company and general manager of the company's Lamp Division, died suddenly March 27 at Asheville, N. C. He was 58.

A veteran of 33 years in the company, Mr. Harroff joined General Electric at Nela Park in 1920, shortly after his graduation from Western Reserve University. He served in the division's Sales Operation Department 10 years and in 1931 was transferred to the Administration Department. In 1943, he was appointed assistant general manager of the Lamp Division and in 1948 was named general manager, succeeding Martin L. Sloan. In 1950 he became vice-president.

During World War II, Mr. Harroff was responsible for coordinating the manufacturing activities of the division. Throughout his career, he devoted much of his effort to the operational analysis of the division's business.

Fluorescent Lamp Ballast Tests
February 3, 1955.

Instruments—1 watt meter; 2 volt meters; 1 voltage regulator; 4 slimline sockets; 2 96-inch T12 fluorescent lamps (new); 2 ballasts (of different manufacturers); 1 light meter.

Input Volts	Ballast "A" Output Volts	Ballast "B" Output Volts	"A" Watts	"B" Watts	"A" Ft-c	"B" Ft-c
110	217	232	175	127	555	430
112	216	230	175	130	564	450
114	214	228	178	135	572	468
116	212	226	182	140	580	485
118	210	224	185	145	587	500
120	209	223	188	148	592	515
122	207	221	192	152	597	527
124	205	220	196	156	603	535
126	204	219	200	160	609	545

Test by C. W. McCormick
Ballast "A" OC — 625 volts
Ballast "B" OC — 775 volts

IT SEEMS TO ME

Fluorescent Ballast Tests

The writer became quite concerned about the "high noise level" inherent in the two-lamp 96T12 fluorescent ballast. The thought that perhaps the line voltage might have a bearing on the noise level developed in the testing of two random ETL-approved ballasts. Each ballast was brought up to operating temperature (free air) and was tested by varying the input voltage in two-volt steps from 110 volts through 126 volts, inclusive. The temperature in the area was 75F. You will note in studying the table the variation in the second voltage, comparatively. In the primary tests, we found the variation in voltage had little or no effect on the noise level of the ballast. Our test unfolded this other data of variation which caused the writer much concern and by adding a light meter to the tests, you see the results in intensity. Looking at an input of 118 volts, ballast "A"'s output is 210 volts; ballast "B"'s is 224 volts; "A" equals 185 watts; "B" equals 145 watts and "A" is 587 footcandles against "B" being 500 footcandles.

Let me state here that the same lamps, instruments and equipment were used for the testing of both "A" and "B" ballasts. Note that there is a difference of 15 per cent in the light output using "A" and "B" ballasts and that there is a difference between "A" and "B" in watts of approximately 22 per cent.

This creates a great problem for the illuminating engineer: not only must he know the line voltage of the lighting systems he is designing, but must know the true wattage output of each ballast and various voltages of each manufacturer's ballast used.

It is suggested that the various ballast manufacturers get together and standardize their equipment to have, eventually, the same operating characteristics and that they publish a chart somewhat similar to the table shown here. C. W. McCormick, *Connecticut Light and Power Co., Berlin, Conn.*

Membership Roster

Permit me to say a fervent AMEN to T. D. Wakefield's letter in March IE, p. 20A.

Even a casual consideration should convince anyone that IES is principally *people*. True we have our technical operations, including both fundamental and applied researches, but even these depend on *people*. Our Section and Chapter meetings and, by and large, our Regional and National Conferences have their greatest importance in association and perhaps emulation of *people*.

Those at headquarters have no trouble locating and identifying (by employment) those *people* they wish to contact, because they have easy access to the records (assuming these may perhaps be up to date). The rest of us must depend almost entirely on memory and our records to do this.

I would suggest that this roster issue be a supplement to one of the early winter numbers. It would then include also a list of the officers and committees, national and local, plus a list of sustaining members. What a valuable compen-

(Continued on page 14A)

(Continued from page 13A)

dium this would be, as it would contain full information, *for* all, about *all* the important *people*.

The issue would not be entirely an additional expense to the Society as some of this material is published anyhow. The extra expense might be financed by a fee which would be paid even by the Members Emeritus. This, however, would defeat the principal objective—to assure that all *people* concerned would have full information about all the other *people* involved. LEONARD V. JAMES, CONSULTING ENGINEER, *513 S. Catherine Ave., La Grange, Ill.*

NEW MEMBERS

At the meeting of the I.E.S. Council held in Phoenix, Ariz., on April 13, 1955, the following were elected to membership. Names marked * are transfers from Associate Member grade.

ALABAMA CHAPTER

Associate Member:
Morrow, W. E., Jr., The M. & A. Electric Co., Gadsden, Ala.

ALAMO CHAPTER

Associate Members:
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GLASS AND ELECTRICITY — Form-free sculpture of neon tubing was shown at the convention of the National Electric Sign Association, in Los Angeles March 6-9. Eight feet high, with 228 feet of neon tubing in three colors, the design is an artistic concept of an electrical impulse, and is entitled "Glass and Electricity." Other suggestions for such designs are bringing up to date the traditional barber pole and cigar store Indian. This sculpture was constructed and shown by Corning Glass Works, Corning, N. Y.

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(Continued on page 16A)

Dollar Bank Savings and Trust Company, Youngstown, Ohio

AGENT: Graybar Electric Company

3rd PRIZE
SCHOOLS AND OFFICES CLASSIFICATION
Lighting Competition Sponsored by
ELECTRICAL CONSTRUCTION & MAINTENANCE

NOTE: 1st, 2nd and 3rd prizes in this classification were all won with Wakefield equipment.

GIVING A NEW LOOK TO THREE ROOMS IN A BANK WITH WAKEFIELD UNITS

by *WILLIAM H. AXELSON, electrical contractor*

William Axelson used three different Wakefield large area lighting units to illuminate the newly remodeled executive suite of the Dollar Bank Savings and Trust Company, Youngstown, Ohio.

RECEPTION ROOM:
A continuous row of Wakefield 4′ x 4′ Beta recessed units in the main part of the room, with twin Beta units in the side offices. Multiple switching gives a range from 60 to 90 footcandles.

BOARD ROOM:
Onto a curved ceiling 15 feet high went a continuous row of Wakefield 4′ x 4′ Omega surface-mounted units to form a pattern complementing the long board room table. Both Betas and Omegas have Rigid-Arch plastic diffusers.

PRESIDENT'S OFFICE:
To top off the decorator's colorful and modern design, a Wakefield translucent ceiling was chosen to give evenly diffused illumination. Above the plastic diffuser are continuous rows of fluorescent lamps on 18 inch centers.

PRAISE FROM MR. AXELSON

"The styling and construction of Wakefield lighting fixtures makes them pleasing to the eye as well as easy to install. The supervisors on both installations remarked about the ease with which the fixtures were installed."

For a new catalog on the Wakefield Ceiling, Wakefield Geometrics and Wakefield luminaires of advanced design, write to The F. W. Wakefield Brass Company, Vermilion, Ohio. In Canada: Wakefield Lighting Limited, London, Ontario.

Wakefield Congratulates WILLIAM H. AXELSON

WAKEFIELD

VERMILION, OHIO — LONDON, ONTARIO

(Continued from page 14A)

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For more information on how this new mercury lamp can fit your operation, call your G-E Lamp supplier, or write General Electric Company, Lamp Division, Dept. 482-IE-5, Nela Park, Cleveland 12, Ohio.

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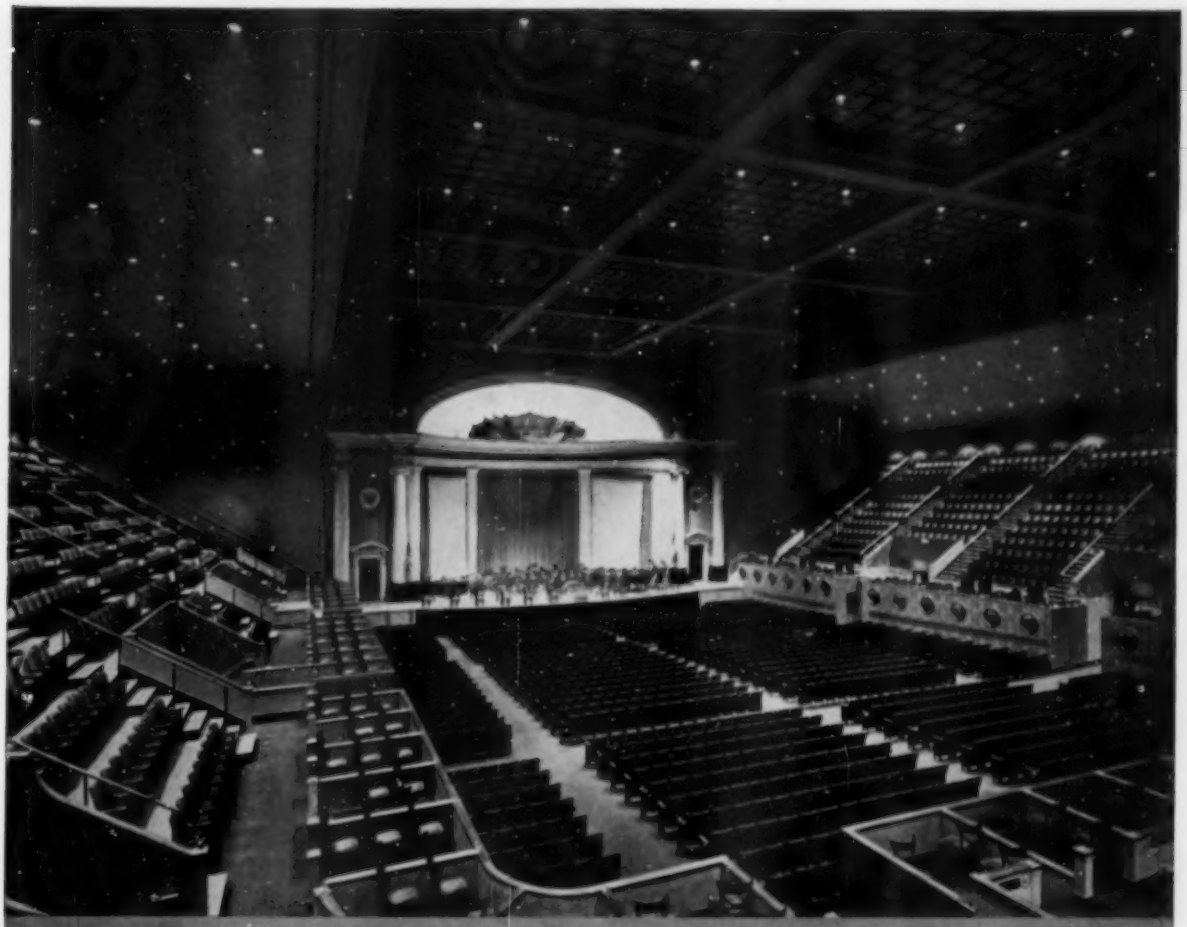

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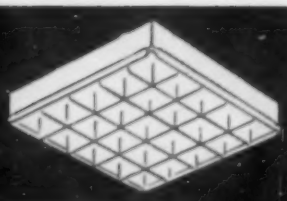

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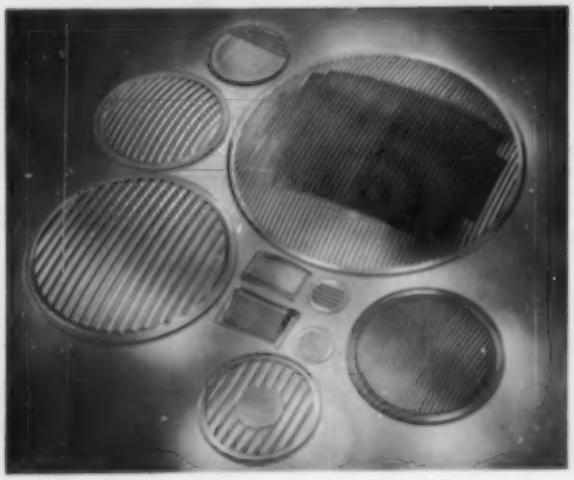

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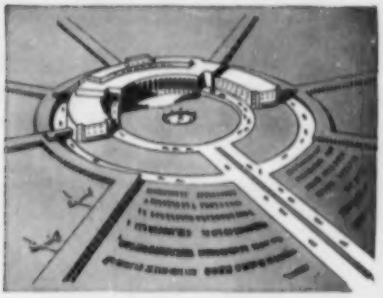

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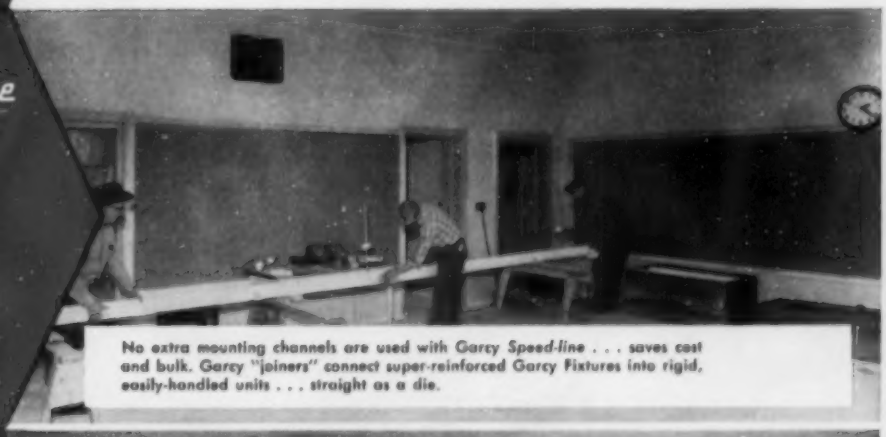

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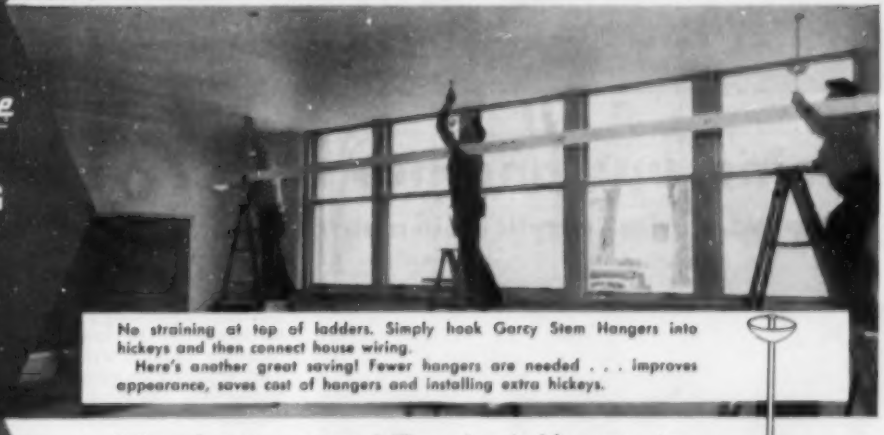
WITH *Speed-line* ENTIRE RUN IS RAISED TO CEILING AS A SINGLE UNIT

. . . and uses fewer stem hangers



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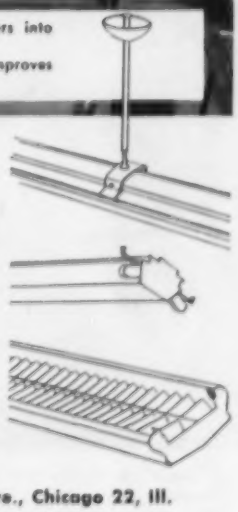
Here's another great saving! Fewer hangers are needed . . . improves appearance, saves cost of hangers and installing extra hickeys.

WITH *Speed-line* YOU CAN DELIVER PREMIUM LIGHTING AT THE COST OF STANDARD FIXTURES

What a boon to contractors! The savings in labor cost enable you to quote a lower total price . . . and still furnish the highest quality commercial fixture made, the Garcy VISUALIER. *Speed-line* installation techniques were specially developed to take full advantage of the Garcy VISUALIER'S unique design features. Separate, lightweight wireways are easiest to handle. The separate, one-piece shielding bodies may be left in cartons, safe from dust and damage, until the job is ready to lamp and light.

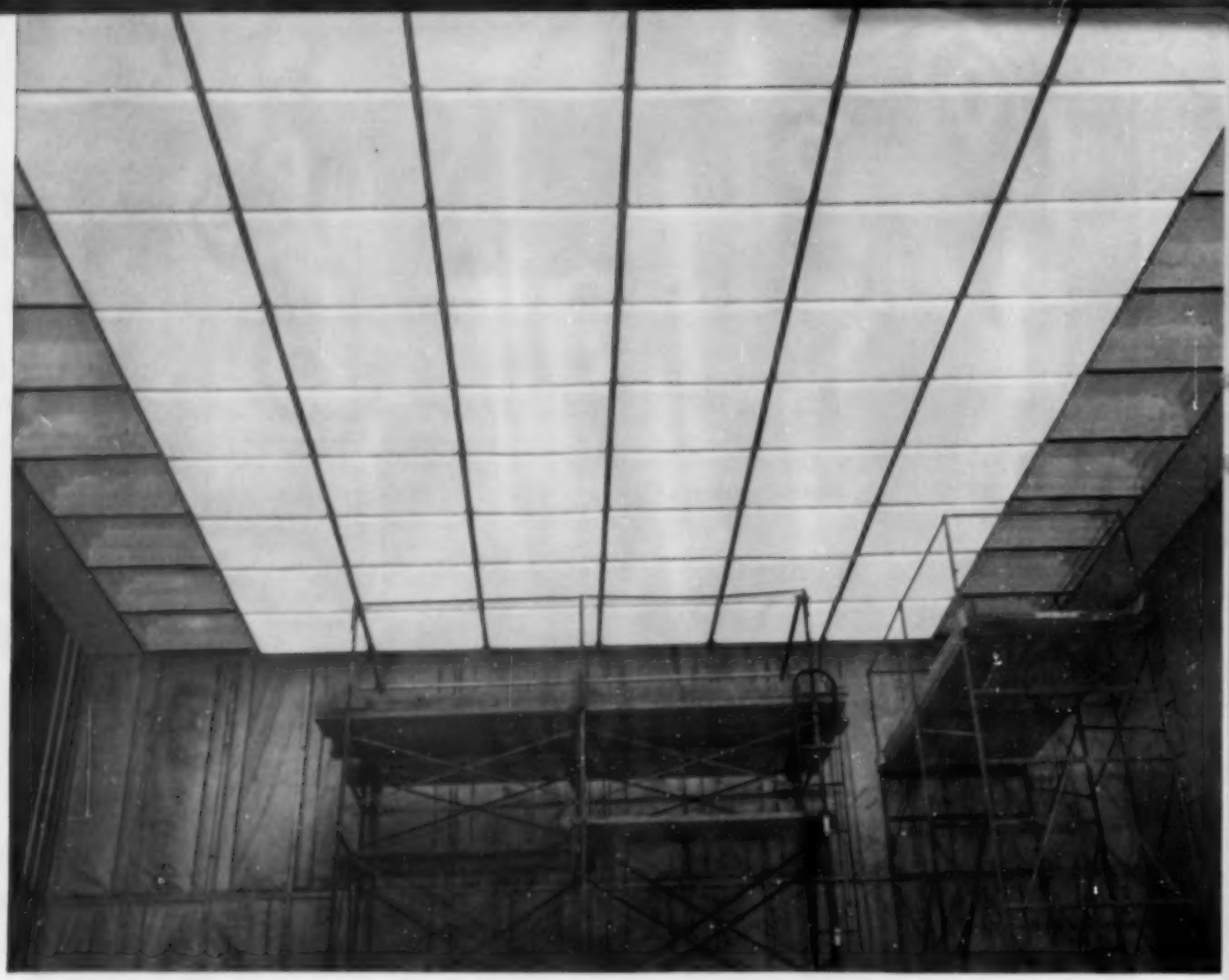
Be the first in your area to offer this contract-winning advance. For budget jobs *Speed-line* is also available with Garcy's Gar-See-Lite fixtures.



Send today for Bulletin 551-L.

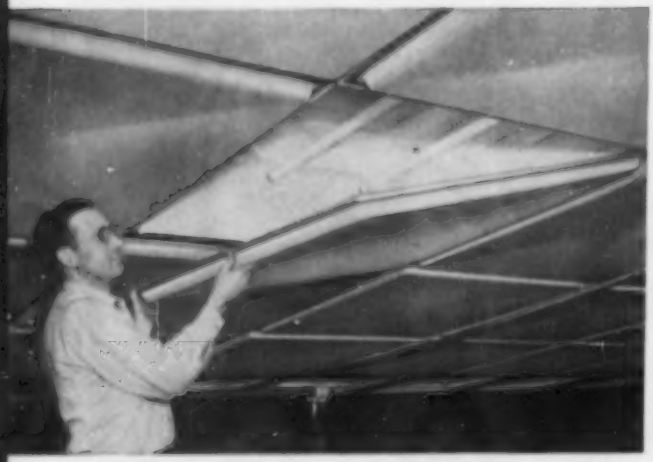
GARCY *Quality by Design*

GARDEN CITY PLATING & MFG. CO., 1760 N. Ashland Ave., Chicago 22, Ill.
In Canada: Garcy Co. of Canada, Ltd., 191 Niagara St., Toronto



Going up: another new ceiling of LUCITE®

Extruded "Lucite" acrylic resin assures harmonious lighting with lasting beauty



"Lucite" is readily and economically fabricated to precise tolerances — even broad sections like this 4' x 4' panel. Fixtures of "Lucite" are lightweight for easy assembly, resist discoloration, are durable.

Luminous ceilings produce the highest level of room illumination with the lowest brightness of light source of any existing lighting system. Today more and more architects and lighting engineers use wall-to-wall lighting diffusers made from Du Pont "Lucite" to achieve maximum lighting efficiency. Comfortable environments are the byword with wall-to-wall lighting that harmonizes well with furnishings.

"Lucite" is available in a variety of transparent and translucent colors designed for specific uses. Parts of "Lucite" are economically made to close tolerances. Two principal methods for efficiently lowering the apparent brightness of light sources are through use of clear refracting prisms and white translucent diffusers of "Lucite." They resist discoloration and breakage . . . are lightweight for easy handling.

For further information on "Lucite" acrylic resin, write to E. I. du Pont de Nemours & Co. (Inc.), Polychemicals Dept., Room 285, Du Pont Bldg., Wilmington 98, Del.

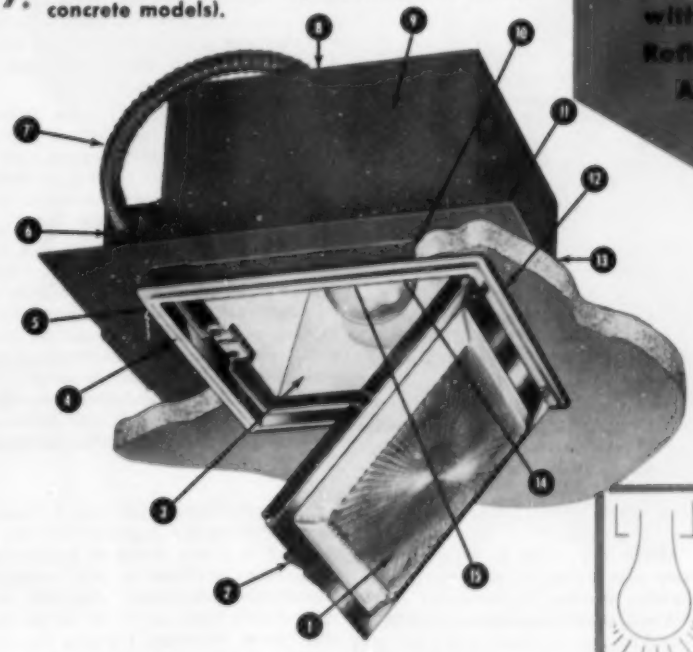
Good Lighting Is Good Business

DU PONT

REG. U.S. PAT. OFF.

BETTER THINGS FOR BETTER LIVING . . . THROUGH CHEMISTRY

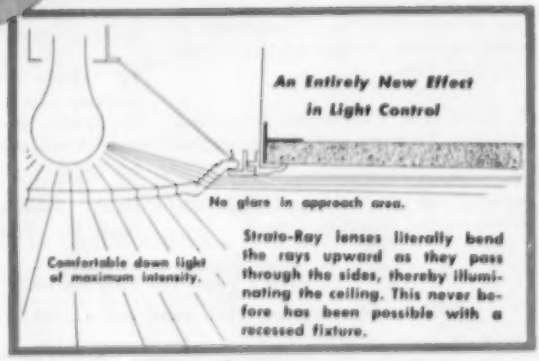
1. Exclusive Pryne-designed Strato-Ray lens combines functional beauty with efficiency.
2. Trip-latch hinged front permits relamping with pole on all vertical lamp models. Tamper proof fronts and lens guard also available.
3. Alzak pyramidal shape reflector. Prevents light leakage.
4. Die-cast zinc frames are finished in polished chrome or white eggshell baked enamel.
5. Weather resistant for outdoor installation in canopies, porches, theatre marquees, etc. (painted rather than plated finish recommended for durability — frames are rust-proof zinc).
6. Standard 4 x 4 inch junction box with ½ and ¾ inch knockouts. Covers removable from either side.
7. Prewired for use with any building wire (except concrete models).



8. Models 2230 and 2232 relamp from top or bottom.
9. Die-formed, heavy gauge galvanized and enameled steel housing.
10. All models fit any finish from ½ to 2 inches thick.
11. Fits 16 inch on center joists, eliminating framing-in.
12. 300 watt models replace one 12 x 12 inch acoustical tile with or without overlap.
13. Lamp housing drops through plaster frame for easy access to junction box.
14. All models available with UL approved auxiliary night light socket.
15. All lamp receptacles have nickel plated copper screw shells.

15 reasons why... Pryne-Liters

with Strato-Ray Lens and Alzak Reflector are the World's Most Advanced Recessed Fixtures


An Entirely New Effect in Light Control
No glare in approach area.
Strato-Ray lenses literally bend the rays upward as they pass through the sides, thereby illuminating the ceiling. This never before has been possible with a recessed fixture.
Comfortable down light of maximum intensity.

pryne

rhymes with FINE . . . and means it!

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Los Angeles; San Francisco; Chicago; Newark, N. J.
Stocked by Leading Wholesalers Everywhere

NEW EQUIPMENT DATA
AVAILABLE WITH COUPON

New manufacturers' catalogs and bulletins listed below are available free to readers of ILLUMINATING ENGINEERING by mailing the coupon. Circle the numbers of those items which you want, drop in envelope or fasten securely to back of 2-cent postcard addressed to Publications Office.

1 Catalog Specification Sheets IND-515 and IND-609 cover respectively this company's line of rapid start fixtures and slimline RLM 20% Uplight fixtures. Sheets give full illumination characteristic data as well as dimensional data. Electro Silv-A-King Corp., Chicago, Ill.

2 New 8-page booklet, "Suntrol Glass Block for Reduction of Glare and Heat," describes the unit recently added to the company's functional glass blocks; shows in detail the physical performance of the new glass block, illustrating the principle of SUNTROL—a pale green diffusing screen that helps to reduce the intensity of glare and heat. Pittsburgh Corning Corp., Pittsburgh, Pa.

3 New catalog C-553 shows line of fluorescent and slimline fixtures for commercial and industrial applications; includes data on dimensions and installations as well as for lighting calculation. Keystone Electric Mfg. Co., Philadelphia, Pa.

4 Folder No. 183 describes directional exit signs and pre-wired recessed lighting fixtures, said to provide faster, more economical installation, service and inspection of commercial and residential recessed lighting. Novelty Lighting Corp., Cleveland, Ohio.

5 Form 578, "Wiremold Fluorescent Lighting Fixtures and Fittings," describes four series of fluorescent and slimline units, presents suggested applications, and is fully illustrated. The Wiremold Co., Hartford, Conn.

6 Booklet on office lighting, "Good Lighting is Good Business," is a factual treatise covering economies and mechanics of good office lighting. The book covers such topics as layout, planning, maintenance, room finishes and color, etc., and includes recommendations for lighting areas other than general offices as well. Sylvania Electric Products Inc., New York, N. Y.

7 Folder describes HYDRO SKY-WORKER, a hydraulically operated boom for carrying workers aloft and maintaining them on a constant work base at any required level; gives full specifications, designs and suggested uses for Models 3852 and 4152. Tey Manufacturing Corp., Milford, Conn.

8 Folder describes Pryne Ventilating Hood, Model 239, a self-contained unit with built-in three-speed fan and light for use over kitchen ranges. Folder gives installation details, describes tilting feature for easy cleaning. Pryne & Company Inc., Pomona, Calif.

9 Two sheets give details on SUN-LITE-AIRE germicidal and ozone lampholder unit for installation in heating or airconditioning systems. Sampson Chemical & Pigment Corp., Chicago, Ill.

10 Attractively covered Brochure 55 contains description of this company's ten lighting systems for industrial, commercial and school installations. Catalog sections have an "architectural" flavor; copy is brief; drawings and tables are clearly presented. The F. W. Wakefield Brass Co., Vermilion, Ohio.

11 Technical Service Bulletin 1 covers static electricity on plastics, describes briefly reason for same and problems, and tells how company's LOGOSTAT products work as combined anti-static and cleaning agent. Logo Inc., Chicago, Ill.

12 Bulletins E and F describe respectively "Permaflector Luminaires and Wall Urns" and "Incandescent with Accessory Lighting Equipment." The former shows incandescent direct and indirect luminaires with full details on distribution and lighting values. Bulletin F shows lighting equipment for indirect, strip, interior spot and interior floodlighting. Pittsburgh Reflector Co., Pittsburgh, Pa.

13 New catalog on company's line of fluorescent lamp ballasts gives full specification and dimensional data and includes series of advertisements showing reproductions of ETL tests on each type. Starring & Co., Inc., Bridgeport, Conn.

14 New LOUVERLITE line is described in two-color folder which emphasizes fixture's 3" depth and gives specifications as to size and number of lamps as well as photometric information and other data. Smitheraft Lighting Division, Chelsea, Mass.

15 New 16-page illustrated bulletin on transformers for mercury lamp street lighting gives general information, lamp data, diagrams and illustrations for both multiple and series circuits, along with installation data; features complete information on "constant wattage" transformers. Jefferson Electric Co., Bellwood, Ill.

16 "Interpretation and Use of Candlepower Distribution Reports," EP 68, is the first in a new series of engineering publications published by this company's photometric laboratory. Bulletin provides helpful hints in the use of distribution curves. Sunbeam Lighting Co., Los Angeles, Calif.

17 Two-color sheet shows line of new YARD LITES describing and picturing three different spiked, portable types for use in home, patio and garden lighting. Markel Electric Products Inc., Buffalo, N. Y.

18 16-page, two-color brochure, "Acousti-Luminus Ceiling — The Ceiling That Works For You," describes and illustrates this company's luminous ceiling; suggests installations and describes features of this type of lighting. Luminous Ceilings Inc., Chicago, Ill.

19 Four-page booklet gives all necessary information for installation and operation of rapid start fluorescent lamps with LUXTROL Light Controls; shows

(Continued on page 30A)

Offer good for two months

Circle numbers wanted. Enter name and address. Clip out and mail.

PUBLICATIONS OFFICE 9-53
ILLUMINATING ENGINEERING SOCIETY
1860 Broadway
New York 23, New York

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Here's lighting economics customers can understand

57¢ is about the price your customer pays for three 50-watt bulbs. 150 watts provide about 1980 lumens.

25¢ is about the price of *one* Sylvania Kitchen Lite. 150 watts . . . 2650 lumens . . . a 34% increase at a 47% saving.

There's simple, down-to-earth economics—and better lighting—for every customer on your lines, with Sylvania's new special-purpose bulb—the 150-watt Sylvania Kitchen Lite.

If you're interested in recommending improved lighting levels to your customers, you may find this Sylvania lamp is the easiest way to put your story across.

LIGHTING • RADIO • ELECTRONICS
TELEVISION • ATOMIC ENERGY

FOR INFORMATION on the Kitchen Lite and other important high-wattage lamps — for information on Sylvania's customer brochures and mailing pieces — contact your nearest Sylvania District Office — or WRITE Dept. 5L-3505, Lighting Division, SYLVANIA ELECTRIC PRODUCTS INC., Salem, Mass. *In Canada: Sylvania Electric (Canada) Ltd., University Tower Building, Montreal.*

SYLVANIA

. . . fastest growing name in sight

MANUFACTURER'S REPRESENTATIVE WANTED

We are seeking top flight lighting representatives.

We are now presently represented in a number of states, but due to our new plant expansion and increase in our fine line, we can comfortably handle additional representatives.

We are manufacturers of a complete line of lighting equipment for commercial, industrial and institutional use, at competitive prices. Specials and equals are fabricated by our plant also.

We are members of the R.L.M. Institute on slimline and fluorescent units and are licensees for various lens concerns.

The representatives we are seeking must be familiar with the electrical wholesalers in his area and in calling on architects and engineers for specification work.

For details, write:

SALES MANAGER

ENDER-MONARCH

CORPORATION

50 Sylvester Street

Westbury, L.I., N.Y.

New Equipment Data

(Continued from page 28A)

complete wiring diagram and explains type of ballasts, sockets and switches to be used; discusses grounding, starting, ambient temperature and noise. Superior Electric Co., Bristol, Conn.

20 Catalog 55 contains company's complete line of fluorescent, slimline and incandescent fixtures, and essential data on footcandle standards, fixture spacing and other data as well as complete specifications on each fixture. Kayline Company, Cleveland, Ohio.

Employment Opportunities

LIGHTING ENGINEER—SALESMAN

Here is an opportunity for the right man to come to Florida to sell lighting fixtures. Must be available for travel and experienced in the complete lighting field. State experience, qualifications and references. Address Box 236, Publications Office, Illuminating Engineering Society, 1860 Broadway, New York 23, N.Y.

SALES ENGINEER WANTED

Nationally accepted manufacturer of complete line of incandescent lighting fixtures seeks services of field representative to call on Architects, Engineers and Distributors. Open territory consists of Virginia and Washington, D. C. Write full details in first letter to Box 238, Publications Office, Illuminating Engineering Society, 1860 Broadway, New York 23, N. Y.

21 New film, "The Sky's the Limit," tells the broad, basic story of UNISTRUT metal framing in color, cartoon animation, musical and special effects, for 16 mm projection. Film shows application and use of metal framing in electrical, mechanical and material-handling and other fields. Information available from company on group use. Unistrut Products Co., Chicago, Ill.

22 Bulletin B-5799-B is new 28-page, pocket-sized catalog of fluorescent luminaires for commercial and industrial use; summarizes features of each type, discusses electrical characteristics, maintenance and mounting data, details of construction, dimensions, and recommendations for application. Westinghouse Electric Corp., Pittsburgh, Pa.

23 Catalog SK-1-53 describes plastic SKY-LITES with extruded aluminum frames, gives 15 reasons for their use and shows installations, dimensional data and prices. Colonial-Hites Co., West Columbia, S. C.

24 Pocket-size, unique corner bound booklet shows company's LUVEX line and pictures a number of schoolrooms, including floor layouts, where these fluorescent fixtures have been used in all parts of the country; offers ideas as to spacing and arrangement, including recommended reflection factors. Day-Brite Lighting Inc., St. Louis, Mo.

25 Catalog for 1955 shows stock and custom fixtures including recessed incandescent, fluorescent under-cabinet lights, recessed and surface fluorescent and exit lights; includes data on new HAP-E LITE. Alkco Manufacturing Co., Chicago, Ill.

26 Catalog page describes new type of low-brightness louver, developed for use with LITE-BLOX recessed troffers. New louver is of parabolic design with precision rolled cross-baffles and said to provide high visual comfort index. Page gives photometric data and full description. The Edwin F. Guth Co., St. Louis, Mo.

27 Four-page, two-color Catalog 530 describes new line of THIN-LITE series of fluorescent luminaires, featuring 2⅝" depth of surface-mounted fixture. Folder gives photometric data as well as dimensional and installation material. Lighting Products Inc., Highland Park, Ill.

28 "Handbook on Modern Stage Lighting Control" is a two-color, 24-page booklet showing company's line of dimmers, stage boards, suggested theater layouts including list of required materials for various locations and suggested sizes of stage boards for various auditoriums. Of interest are two pages of stage-studio terminology. Metropolitan Electric Mfg. Co., Long Island City, N.Y.

Get These ABOLITE Features At No Extra Cost

SLOTTED-NECK construction is an original ABOLITE feature! It keeps lamps cooler (40° cooler on a 1000 Watt lamp) — increases lamp life—reduces maintenance. ABOLITE SLOTTED-NECK reflectors keep dirt and dust on the move — they eliminate grime accumulation and maintain better reflectivity over a longer period of time.

ABOLITE ALL-WHITE finish, outside and inside, is the whitest Titanium white porcelain enamel ever developed. This new ALL-WHITE finish will not rust or stain, is impervious to the effects of weather, oil, grease and fumes, and gives plants a clean, modern, efficient appearance.

WHITER THAN WHITE — ABOLITE Lighting

Get these original ABOLITE features at no extra cost.

•

THE JONES METAL PRODUCTS CO.

West Lafayette, Ohio

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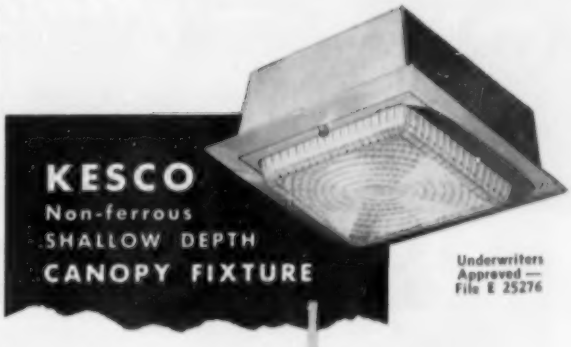


KESCO
Non-ferrous
SHALLOW DEPTH
CANOPY FIXTURE

Underwriters Approved — File E 25276

KESCO recessed canopy fixtures are ideal for installation in poured concrete exterior canopies, where rugged construction, shallow depth, and durable finish and materials are requirements.

- 4½" Depth
- 10¼" Square
- 7/32" Wall Thickness
- Cast Aluminum Box
- Separately Detachable Two-Piece Satin Finish Cast Aluminum or Bronze Frame
- Drop Hinge Assembly for Easy Bulb Replacement and Cleaning
- Approved for One 150-Watt Incandescent Lamp
- Flat or Drop-lens Type

KESCO Catalog Now Available
Write For Your Free Copy Today

Manufacturers Representatives:
A limited number of territories are still open. We invite your inquiry.

KESCO

K-E SALES CORPORATION
P.O. Box 2228 Gardner Station
St. Louis 9, Mo.

ORNAMENTAL LIGHTING FIXTURES

Genuine Bronze and Wrought Iron

We are "just your size"—big enough to produce any lighting-fixture job, however intricate or extensive; small enough to give every job our personal attention and supervision, and to produce lighting equipment of the finest character in every detail.

MEIERJOHAN-WENGLER
1102 W. 9th St. CINCINNATI 3, OHIO

Estimates and literature sent on request.

SOLA *Lighting* TRANSFORMERS

SOLA ELECTRIC CO. • 4633 West 16th Street
Chicago 50, Illinois • BIshop 2-1414

The complete line of Sola lighting transformers is described by the six units listed below. It is suggested that your specifications file be checked against the bulletin numbers given. On your request Sola Electric Co. will be happy to provide those current bulletins you desire. By specifying that your name be placed on Sola's "Lighting" Mailing List, you will be assured of receiving future bulletins as they are issued.

Fluorescent BALLASTS

All Sola Fluorescent Ballasts feature pressed-in core construction. This method results in uniformity of electrical characteristics. It also produces a core-and-coil assembly that is extremely quiet since vibration due to loose fitting parts is virtually eliminated. Sola ballasts are varnish impregnated under high vacuum and progressively compounded for quiet, reliable operation. They are designed and manufactured as premium quality ballasts.

Ballasts For Rapid-Start Lamps

- High Power Factor Ballasts for 60 cycle, two-lamp operation.
- Patented constant wattage circuit maintains light output constant within ±2% over primary range of 106-130v.
- Peak to RMS ratio is only 1.51, better by 15% over maximum A.S.A. specifications.
- 300v from lamp to starting aid for positive starting with absolute safety.

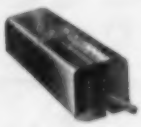
WRITE FOR SPECIFICATION BULLETIN 3E-FLI99

Ballasts For Indoor Applications of Slimline and Instant-Starting Lamps

- High Power Factor Ballasts, 60 cycles, 106-130v.
- Sequenstart Ballasts for series-sequence operation, and Dynatran Ballasts for lead-lag operation of two instant-start hot cathode fluorescent lamps.
- Slimline Ballasts for operation of single instant-start hot cathode fluorescent lamps.

WRITE FOR SPECIFICATION BULLETIN 3E-FLI86A

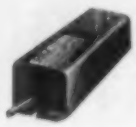
Ballasts For Outdoor Applications of Slimline and Instant-Starting Lamps



- Specifically designed for outdoor non-weatherproof applications.
- Special low temperature capacitors and moisture-resistant wire leads.
- Positive starting and operating temperature characteristics ideal for wide range of conditions found in outdoor non-weatherproof use such as plastic signs, canopy fixtures and pylons.

WRITE FOR SPECIFICATION BULLETIN 3E-FLI96A

Ballasts For Cold Cathode Lamps



- High Power Factor Ballasts for 93 inch, 25mm. diameter cold cathode lamps operating at 106-130v., 60 cycles.
- All indoor types have constant wattage circuit. Outdoor non-weatherproof types with constant wattage or non-regulating circuit.
- Constant wattage types maintain light output within ±2.5% with input variations as great as ±15%. Operation maintained close to unity power factor, even when one lamp is inoperative on two-lamp parallel ballast.

WRITE FOR SPECIFICATION BULLETIN 3E-FLI52A

Mercury Vapor Lamp TRANSFORMERS

Constant wattage and conventional non-regulating mercury vapor lamp transformers are available for indoor and outdoor commercial and industrial applications. Constant wattage types regulate light output and lamp wattage regardless of line voltage fluctuations . . . eliminate need for primary taps . . . provide open and short circuit protection . . . extend lamp life.

Transformers For Indoor Applications

- Constant wattage and conventional non-regulating types.
- Single-lamp or two-lamp operation of 400, 700 and 1,000 watt mercury vapor lamps.
- Constant wattage types maintain light output constant within ±2% with line voltage variations as great as 25%.
- Compact, suitable for mounting in any manner.

WRITE FOR SPECIFICATION BULLETIN 3E-MV211 for CW types and SPECIFICATION BULLETIN 3E-MV214 for non-regulating types.

Transformers For Outdoor Applications

- For 1-400 Watt Type H1 Mercury Vapor Lamp.
- Constant wattage circuit maintains light output constant within ±2% with line voltage variations as great as 25%.
- Outages virtually eliminated since primary voltage must drop below 70 volts before lamp extinguishes.
- Positive starting within primary ranges of 100/200- 130/260v without taps.

WRITE FOR SPECIFICATION BULLETIN 3E-MV208

Those who really know say:

CERTIFIED CBM CERTIFIED by ETL BALLASTS

give best results!

• No one knows better the value of CERTIFIED CBM BALLASTS than the manufacturers of fluorescent tubes. For the satisfactory performance of their lamps is vitally dependent on the ballasts that operate them. They know CERTIFIED CBM BALLASTS are Tailored to the Tube.

CHAMPION *says:*

"Fluorescent lamps are designed to operate at specific electrical values. The use of auxiliary equipment that has been proven to meet these agreed upon standards will assure the user maximum value for his lighting dollar with a minimum of operational failures. Certified Ballasts are inexpensive insurance."

GENERAL ELECTRIC *says:*

"The life and light output ratings of fluorescent lamps are based on their use with ballasts providing proper operating characteristics. Ballasts that do not provide proper electrical values may substantially reduce either lamp life or light output, or both. Ballasts certified as built to the specifications adopted by the Certified Ballast Manufacturers (CBM) do provide values that meet or exceed minimum requirements. This certification assures the lamp user, without individual testing, that lamps will operate at values close to their ratings."

SYLVANIA *says:*

"The light and life ratings of fluorescent lamps are based on three hour burning cycles under specified conditions and with ballasts meeting American Standards Association specifications. Ballasts marked with the CBM emblem and certified by Electrical Testing Laboratories, Inc., meet ASA specifications."

WESTINGHOUSE *says:*

"Use ballasts that are tested and Certified by Electrical Testing Laboratories or ones that are otherwise known to meet the specifications of the lamp manufacturer. These will give best results with Westinghouse fluorescent lamps."

That's why CERTIFIED CBM BALLASTS merit the slogan—Tailored to the Tube.

Certified CBM Ballasts are built to assure quiet operation and long trouble-free life.

CERTIFIED BALLAST MANUFACTURERS

Makers of Certified Ballasts for Fluorescent Lighting

2116 KEITH BLDG., CLEVELAND 15, OHIO

2,200 GUTH TROFFERS CREATE AN "ACRE OF LIGHT" AT LOVEMAN'S

Shoppers are greeted by a store full of lighting that says "come in and buy" as they enter Loveman's Department Store, Montgomery, Alabama.

Nicknamed "an acre of light", this beautiful new store has over 86,000 sq. ft. of sales area. Every inch is efficiently lighted by 2,200 Guth Recessed Troffers and 265 Guth Tile-Lites. Tile-Lites were used between fixtures and at row ends for added interest in the long lines of light.

This striking troffer installation looks as if it were custom-made for Loveman's. The fixtures blend harmoniously with the modern decor. Gleaming snap-on trim hides flange screws and "teebar gap" for a distinctive, tailored appearance. The effect of "arrow-straight lines of light" was made possible by the precision alignment of the troffers.

In a job this size, installation work is a big factor. According to the electrical contractor, this "acre of light" was . . . a breeze . . . one man could have handled it! The fixtures arrived in complete units . . . ready to mount. They fitted the "tile-wide" openings perfectly.

The troffers, with 35° x 30° metal eggcrate shielding provide 40 F. C. halfway between rows. Readings were taken at 34" above the floor.

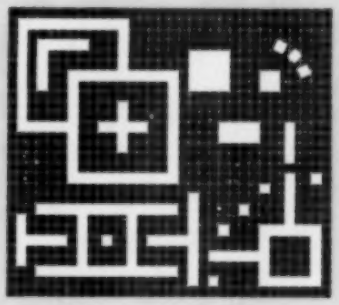
Another factor in the choice of Guth Troffers was maintenance economy. They have hinged shield frames for easy relamping or cleaning. Slide-in reflectors are simple to remove. Electrical apparatus may be replaced without taking troffers down.

Loveman officials give a great deal of credit to Guth Lighting for making their store a pleasant place to work, to shop . . . and to make profits!

Loveman's is part of the new Normandale Shopping Center—33 shops and stores, all lighted with Guth Troffers. It was developed by Aronov Realty Co., Inc.; Architect, Sherlock, Smith & Adams; Electrical Engineer, J. L. Phillips; Electrical Contractor, Long & McGhee Elec. Co.; General Contractor, Jehle Brothers, Inc.; Distributor, Noland Company, Inc.

Guth

LITE-BLOX TROFFERS
for sparkling lines of efficient light in any office or store
(See Loveman Article at left)



The most complete troffer line—

2 x 2's, 2 x 4's, 4 x 4's for unlimited pattern planning.

All types of shields from GrateLite* Louver-Diffuser to the new Paraflector and "Ro-Lo-B" Louvers.

WRITE ON YOUR LETTERHEAD TODAY FOR BIG NEW GUTH TROFFER CATALOG 50-I! FREE!

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